BY ORDER OF THE
SECRETARY OF THE AIR FORCE

AIR FORCE MANUAL 11-217, VOLUME 2
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Flying Operations

INSTRUMENT FLIGHT PROCEDURES

This instruction implements AFPD 11-2, Flight Rules and Procedures, by providing guidance and procedures for standard Air Force instrument flying. Since aircraft flight instrumentation and mission objectives are so varied, this instruction is necessarily general regarding equipment and detailed accomplishment of maneuvers. Individual aircraft flight manuals should provide detailed instructions required for particular aircraft instrumentation or characteristics. This instruction, when used with related flight directives and publications, provides adequate guidance for instrument flight under most circumstances, but is not a substitute for sound judgment. Circumstances may require modification of prescribed procedures. Aircrew members charged with the safe operation of United States Air Force aircraft must be knowledgeable of the guidance contained in this manual. This publication applies to the Air National Guard (ANG) when published in the ANGIND 2.

Paragraph

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Tables

Chapter 1

GLOBAL POSITIONING SYSTEM (GPS)

1.1. Global Positioning System (GPS).

1.1.1. General Description of DoD's Global Positioning System (GPS).

- **Spaced-Based System.** The global positioning system (GPS) is a space-based navigation system which provides highly accurate three-dimensional navigation information to an infinite number of equipped users anywhere on or near the Earth. The typical GPS integrated system will provide: position, velocity, time, altitude, steering information, groundspeed, ground track error, heading, and variation.
- **Levels of Accuracy.** GPS measures distance by timing a radio signal that starts at the satellite and ends at the GPS receiver. The signal carries with it data that discloses satellite position and time of transmission, and synchronizes the aircraft GPS system with satellite clocks. There are two levels of accuracy available: Coarse acquisition (C/A) data will provide position accurate to within 100 meters and can be received by anyone with a GPS receiver; precision (P) data can be received only by authorized users in possession of the proper codes, and its data is accurate to within 16 meters.

1.1.2. GPS Segments. GPS is composed of three major segments: space, control, and user.

- **Space Segment.** The GPS constellation is composed of multiple satellites whose orbits and spacing are arranged to optimize the GPS coverage area.
- **Control Segment.** The control segment includes a number of monitor stations and ground antennas located throughout the world. The monitor stations use GPS receivers to track all satellites in view and accumulate ranging data from the satellite signals. The information from the monitor stations is processed at the master control station (MCS) and is used to manage the satellite system.
- **User Segment.** The user segment consists of GPS equipment used in a variety of ways: aircraft avionics, surveying equipment, handheld GPS receivers, etc ... GPS equipment uses data transmitted by the satellites to provide instantaneous position information.

1.1.3. Integrated Systems. Integration of GPS into each aircraft's navigation system will vary depending on the mission of the aircraft. GPS can greatly enhance the performance of an INS, and the INS, in turn, increases the usefulness of GPS equipment. INS has the ability to accurately measure changes in position and velocity over short periods of time using no external signal; however, errors are cumulative and increase with time. GPS can provide a continuous position update which allows the INS to calculate error trends and improve its accuracy as time increases. The INS aids the GPS receiver by improving GPS position predictions between position updates as well as improving system anti-jam performance. When GPS is not available (due to mountain shadowing of satellites, jamming, or high dynamic maneuvers), the improved INS will provide the integrated navigation system with accurate position information until the satellites are back in view or the jamming is over. GPS can also provide in-flight alignment capability for the INS.

1.1.4. Course Sensitivity. The Course Deviation Indicator (CDI) sensitivity related to GPS equipment varies with the mode of operation and the type of equipment. (Refer to your flight manual.) Unlike traditional ground-based NAVAIDs, GPS course sensitivity is normally linear regardless of the distance from the waypoint. Typically, the following modes provide the indicated CDI scaling:

- **Enroute Mode.** Enroute phase, prior to the execution of the instrument approach, the display sensitivity full scale deflection is 5 nm either side of centerline.

- **Terminal Approach Mode.** Upon activation of the approach mode, the display sensitivity should smoothly transition from a full scale deflection of 5 nm either side of centerline to 1 nm either side of centerline within 30 nm of the destination airport. The approach mode must be active to proceed past the final approach fix on a non-precision approach.
- **Final Approach Mode.** At a distance of 2 nm inbound to the FAF waypoint, the display sensitivity begins to transition to a full scale deflection of 0.3 nm either side of centerline. Some GPS avionics may provide an angular display between the FAF and MAP that approximates the course sensitivity of the localizer portion of an ILS.
- **Missed Approach Mode.** When navigation to the missed approach holding point is activated, the CDI display sensitivity transitions back to terminal area sensitivity (±1 nm).

1.2. Restrictions on the Use of GPS. Specific GPS equipment capabilities vary widely from aircraft to aircraft; therefore, all pilots must be thoroughly familiar with the GPS equipment installed in their aircraft, its authorized use and its limitations. Some USAF aircraft are not capable of performing all of the activities described in this chapter. Aircrews must consult AFI 11-206, this manual, MAJCOM flight directives and the aircraft technical order to fully determine the capabilities of their aircraft's GPS equipment and restrictions on its use.

1.2.1. Use of GPS Outside of the U.S. National Airspace System (NAS). GPS use may be further restricted depending on the area of operation. Flight using GPS is not authorized in some countries. If you plan to use GPS outside the National Airspace System (NAS), check for additional restrictions in FLIP's General Planning (GP) and Area Planning (AP) documents in your area of intended operation.

1.2.2. Integrity Monitoring. GPS equipment certified for IFR use must have the capability of verifying the integrity of the signals received from the GPS constellation. The integrity of the GPS signal is verified by determining if the integrity solution is out of limits for the particular phase of flight, if a satellite is providing corrupted information, or if there is an insufficient number of satellites in view. When the integrity of the GPS information does not meet the integrity requirements for the operation being performed, the aircraft's GPS avionics will provide a warning in the cockpit. A GPS integrity warning in the cockpit is equivalent to an "off flag" on your HSI; your GPS navigation information may no longer be reliable. Refer to your aircraft tech order for specific information regarding your GPS avionics.

1.2.3. Database Requirements. To use GPS for IFR navigation in the terminal area or for GPS non-precision approaches, the aircraft's GPS equipment must include an updatable navigation database. GPS airborne navigation databases may come from the Defense Mapping Agency (DMA) via the mission planning system or from an approved commercial source.

- **Manual Database Manipulation.** Manual entry/update of the validated data in the navigation database is not possible; however, this requirement does not prevent the storage of "user-defined data" within the equipment.

1.2.4. RNAV in the Terminal Area. Restrictions on the use of RNAV in the terminal area are contained in paragraph 7.11.3 of AFMAN 11-217, Volume 1. Some GPS equipment will provide the capability to use RNAV procedures in the terminal area. Using GPS equipment as the sole navigation source for RNAV in the terminal area is only permitted if all of the waypoints defining the route of flight can be retrieved from the aircraft's GPS navigation database. GPS sole-source navigation using user-defined waypoints may not be used after the initial approach fix (IAF) or prior to the termination point of a standard instrument departure (SID). GPS equipment may be used to identify IAF on IAPs and the termination point on SIDs.

1.2.5. GPS Approaches. There are basically two types of GPS approaches: "stand alone" approaches and "overlay" approaches.

1.2.5.1. GPS "Stand Alone" Approaches. GPS "stand alone" approaches are constructed specifically for use by GPS and do not have a traditional underlying procedure. GPS stand alone approaches are identified by the absence of other NAVAIDs in the approach title; for example, GPS RWY 35.

1.2.5.2. GPS "Overlay" Approaches. GPS "overlay" approaches permit some pilots to use GPS avionics under IFR to fly existing instrument approach procedures. Most overlay approaches are at civil fields and because of charting and database discrepancies, USAF aircraft are not authorized to fly GPS overlay approaches. Overlay approaches can be identified in two ways.

- **GPS Not in the Title.** Some approaches (typically VORs and NDBs) don't have GPS in the title, yet they are coded into the database and are retrievable and, therefore, qualify as a GPS overlay approaches. For example, if your equipment allows you to retrieve and arm an approach named "VOR RWY 35," then the VOR RWY 35 is an overlay approach.
- **"Or GPS" in the Title.** If the approach has the phrase "or GPS" in the title, then it is a GPS overlay approach; for example, VOR or GPS RWY 12.

1.2.6. Portable GPS Units (PGUs). MAJCOMs may authorize the use of portable GPS units (PGUs) on some passenger-carrying aircraft as an aid to situational awareness. Experience has shown that the improper use of handheld GPS receivers can lead to distraction and loss of situational awareness. PGUs are not authorized for IFR navigation, instrument approaches, or as a primary flight reference. For further guidance regarding PGUs, refer to AFI 11-206 and MAJCOM flight directives.

1.2.7. Alternate Requirements. Currently, GPS is a supplemental means of navigation; therefore, in order to meet the published approach requirements of AFI 11-206, alternate airports must have a published instrument approach, other than GPS, which is anticipated to be operational and available at the estimated time of arrival.

1.3. Aircrew Actions.

1.3.1. Preflight.

- **Check NOTAMs.** Prior to a flight using GPS, review NOTAMs by referring to the installation NOTAMs for your destination and any alternates.
- **File the Appropriate Equipment Suffix.** Aircraft navigating using GPS are considered to be RNAV-equipped aircraft and the appropriate equipment suffix should be included on the flight plan. Consult FLIP General Planning for the proper equipment suffix for your aircraft.
- **GPS Equipment Checks.** Check GPS ground equipment by following the specific start-up and self-test procedures for the GPS receiver or Flight Management System (FMS) as outlined in the aircraft technical order. Check the currency of your database, and if your equipment has predictive integrity capability, check the expected integrity for the approach you plan to fly.

1.3.2. Terminal Area Operations - Departure.

- **Load SID.** If a SID is to be flown, load the appropriate SID by retrieving the route from your navigation database. If the SID cannot be retrieved from the database, then you may not use RNAV procedures to fly it prior to the SID termination point.
- **Terrain Avoidance.** Regardless of the method used to navigate the SID, the pilot is still responsible for terrain and obstacle avoidance as well as any ATC-required climb gradients.
- **Terminal Sensitivity.** When flying a SID using GPS, the pilot must ensure the terminal sensitivity mode is selected to ensure the correct scaling of the CDI (± 1 nm).

1.3.3. Enroute Operations.

- **Use of Predictive Integrity.** If your aircraft has the capability to predict the GPS integrity level, while you are enroute to your destination, check the expected integrity for the planned approach. If your check indicates the appropriate integrity for the planned operation may not be available, develop an alternate plan for landing at the airfield or proceed to your alternate.
- **Traditional Avionics Requirements.** When using an IFR-approved GPS system for enroute navigation, aircraft must have navigation equipment capable of receiving the ground-based NAVAIDs (which must be operational) required to fly the planned route to the destination airport and any required alternate. The purpose of the ground-based systems is to ensure that the aircraft can continue to the destination if something unforeseen occurs to the avionics or the GPS constellation. USAF aircraft will crosscheck GPS with traditional ground-based NAVAIDs.

1.3.4. Prior to Descent.

- **GPS Approach Briefing.** Thoroughly brief the entire GPS instrument approach procedure including the missed approach instructions. Compare the approach retrieved from the GPS navigation database to the instrument approach procedure published on your approach plate. Should differences between the approach chart and database arise, the published approach chart, supplemented by NOTAMs, takes precedence.
- **Develop a Backup Plan.** Develop a backup plan to use in case of GPS or GPS integrity failure. Pay particular attention to ground-based NAVAIDs which can be used to help maintain position awareness. Be sure to consider the possibility of equipment failure past the FAF.
- **Load STAR.** If a STAR is to be flown, load the appropriate STAR by retrieving the route from your navigation database. If the STAR cannot be retrieved from the database, then you may not use RNAV procedures to fly the procedure. Additionally, terminal area routing which cannot be retrieved from the navigation database may not be used.

1.3.5. Terminal Area Operations - Arrival.

- **Maintain Situational Awareness.** As you prepare to enter the busy environment of the terminal area, it is important to maintain a high level of situational awareness using all available means. Monitor all ground-based NAVAIDs that are available to you (bearing pointers, DME, etc.) since GPS approaches are flown point to point. On most aircraft, the bearing pointer and distance measurement on your HSI will be to the next waypoint, not necessarily to the field.
- **Be Prepared to Use Traditional NAVAIDs.** Experience has shown situational awareness can deteriorate when flying GPS approaches if the sequence of events does not go as planned. Be prepared to go to your backup plan if you become disoriented while flying the GPS approach.

- **Be Wary of "Heads-Down."** Depending on your aircraft's GPS equipment, operating with GPS in the terminal area tends to be more "heads-down" than normal—especially when things do not go as planned. Being intimately familiar with your GPS equipment and thorough approach preparation will help you clear for other traffic.
- **GPS is a New Form of Flying.** Flying GPS approaches involves a new way of flying for most USAF pilots. Setting up a GPS receiver for an approach involves at least as many operations as are required to configure traditional navigation equipment. The sequence of events is critical to success. Setup routines are not intuitive and they vary significantly from one manufacturer to the next. Pilots must be thoroughly familiar with their equipment before flying GPS approaches in IMC.

1.3.6. Preparing for the Approach.

1.3.6.1. Select the Appropriate Procedure. To begin the GPS approach, select the appropriate airport, runway, instrument approach procedure, and initial approach fix.

- **Database.** The IAP must be retrieved from the GPS navigation database.
- **Pilot-Defined Approaches.** GPS approaches using pilot-defined points are not authorized.

1.3.7. Performing the Approach.

1.3.7.1. Arming the Approach Mode.

- **Prior to the IAF.** "Arm" the approach mode prior to the IAF. Arming the approach mode will allow your GPS equipment to automatically change from enroute sensitivity (± 5 nm) to terminal sensitivity (± 1 nm) once the aircraft is 30 nm from the airfield.
- **Inside of 30 nm.** If you do not arm the approach mode prior to 30 nm from the airport, then your GPS equipment will generate a warning once your aircraft is 30 nm from the airport.
- **3 NM Prior to the FAF.** Approximately 3 nm prior to the FAF, your equipment will alert you that display sensitivity is about to change again. At 3 nm, if you still haven't armed the approach mode, it will give you another warning.
- **Ramp Down.** Beginning 2 nm prior to the FAF, your equipment will (if previously armed) automatically switch from terminal integrity performance (± 1 nm) to approach integrity performance (± 0.3 nm). This change in sensitivity is called "ramping down," and depending on your equipment, will occur between 2 nm prior to the FAF and the FAF.

NOTE: Pilots must ensure the equipment has switched from the "armed" mode to the "active" mode by the time the aircraft reaches 2 nm from the FAF. Failure to sequence may be an indication of integrity failure, failure to arm, or some other type of failure.

- **2 NM Lockout.** At 2 nm, if you still have not armed the approach mode, your equipment will not let you fly the approach. Your equipment will "flag," and GPS navigation guidance will not be provided beyond the FAF.
- **GPS Integrity Warning Prior to FAF.** If a GPS integrity warning occurs prior to the FAF, the pilot should proceed to the MAP via the FAF, perform a missed approach, and notify ATC as soon as possible. The approach mode must be deselected prior to the FAF or all navigation guidance may be lost at the FAF. Pilots must be especially careful to remain on centerline since CDI scale sensitivity is now greater than the size of the primary protected airspace.

1.3.7.2. Final Approach.

- **Descent to MDA.** Do not descend to the minimum descent altitude (MDA) or step down fix altitude until passing the FAF.
- **Visual Descent Point (VDP).** If a VDP is not depicted on the approach plate, compute a VDP for your aircraft prior to leaving the FAF. Plan your descent so that you arrive at the MDA at or prior to the VDP—this should ensure you can identify the runway environment with enough time to depart the MDA in order to touch down at a rate normally used for a visual approach in your aircraft.
- **Runway Environment.** Descent below MDA is not authorized until sufficient visual reference with the runway environment has been established and the aircraft is in a position to execute a safe landing. Thorough preflight planning will aid you in locating the runway environment (lighting, final approach displacement from runway, etc.).
- **Vertical Navigation.** Some aircraft avionics provide a computed vertical path for GPS non-precision approaches. Regardless of the type of equipment being used, in all cases, USAF pilots must comply with all altitudes (i.e., stepdown fixes, minimum descent altitude, etc.) depicted on the IAP.
- **GPS Integrity Warning After the FAF.** A GPS integrity warning occuring after the FAF is a serious situation and pilots must be prepared to take immediate action. Transition to your backup approach (if available) or proceed to the MAP along the final approach course and execute the missed approach via the route and altitudes specified in the published missed approach procedure or comply with ATC instructions.

1.3.8. Performing the Published Missed Approach Procedure.

- **Missed Approach Point (MAP).** The missed approach point will be labeled on the approach plate by a named waypoint.

- **Select Missed Approach Mode.** At the MAP, the equipment will not automatically sequence to the next required waypoint; therefore, the pilot must manually sequence the GPS equipment to the next waypoint. At the MAP, the pilot must manually sequence into the missed approach mode which will change the CDI scaling from approach (± 0.3 nm) to terminal (± 1 nm) sensitivity.
- **Performing the Missed Approach.** If the missed approach is initiated prior to the MAP, proceed to the MAP along the final approach course and then via the route and altitudes specified in the published missed approach procedure or comply with ATC instructions.
- If the missed approach procedure includes a turn, do not begin the turn prior to the MAP. The obstacle clearance area provided for the missed approach is predicated upon the missed approach being started at the MAP.

1.3.8.1. Piloting Procedures.

- **Missed Approach Climb Gradient.** Regardless of the method used to navigate the missed approach procedure, the pilot is still responsible for terrain and obstacle avoidance as well as any ATC-required climb gradients. In order to avoid obstacles, pilots must plan to climb at a minimum gradient of 152 feet/NM unless a higher gradient is published.
- **Equipment Peculiarities.** Pilots must be aware of how their aircraft's GPS equipment works. For example, if the published missed approach procedure is to "climb on runway heading to 2,000' MSL; then turn right and proceed direct to SHAKI," then your equipment may not turn you towards SHAKI until the aircraft reaches 2,000' MSL. Depending on your rate of climb, your GPS equipment could turn you to SHAKI early (or late) which may put your aircraft outside the TERPs protected airspace.

Chapter 2

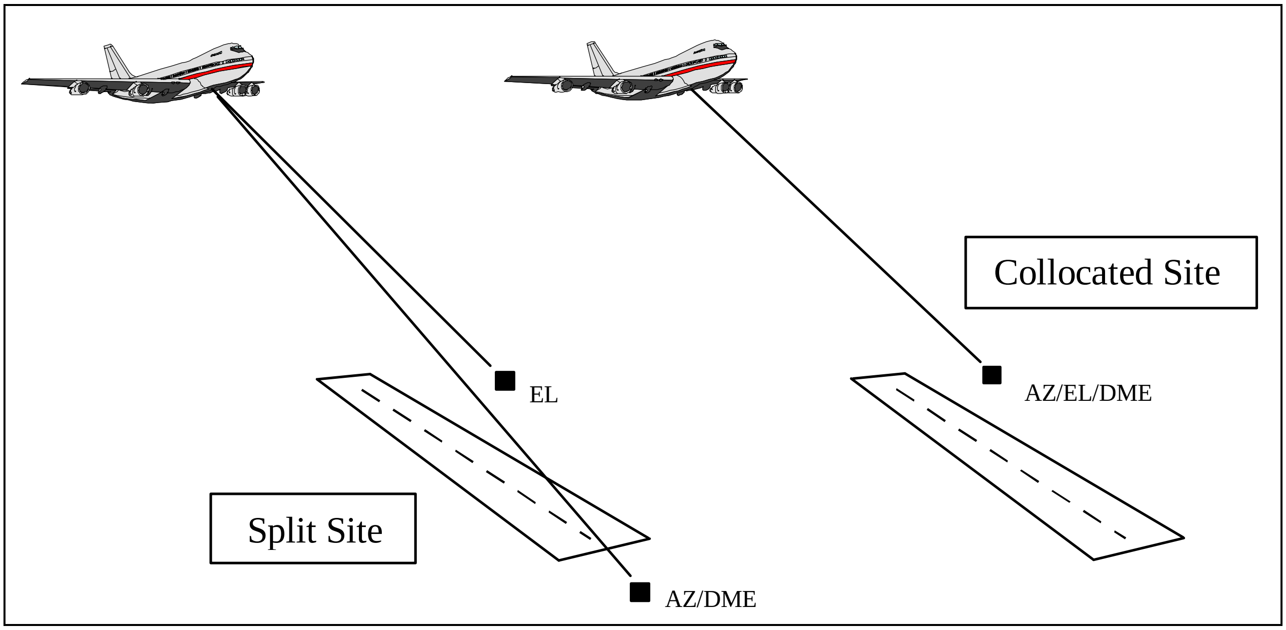
MICROWAVE LANDING SYSTEM (MLS)

2.1. Microwave Landing System (MLS).

2.1.1. Description. The MLS provides precision navigation guidance for exact aircraft alignment and descent during an approach to a selected runway. It integrates azimuth (AZ), elevation angle (EL), and range (DME) information to provide precise aircraft positioning. The components of an MLS are similar to an ILS. Instead of a glideslope antenna, the MLS has an elevation station, and instead of a localizer antenna, it has an azimuth station. The MLS also has a precision DME (DME/P) transmitter. The DME/P signal is more accurate than traditional DME.

- **Ground Equipment Location (Figure 2.1).** MLS is normally installed in a configuration quite similar to ILS; however, it is possible, if necessary because of limited space, to install all of the components together. One example of this type of collocated configuration might be a hospital's heliport. In a standard airfield installation, the MLS azimuth transmitter is usually located between 1,000 and 1,500 feet beyond the departure end of the runway along the runway centerline. The elevation transmitter is normally located 400 feet from the runway centerline near the approach threshold. The DME, which provides range information, is collocated with the azimuth transmitter.

Figure 2.1. MLS Ground Facility Configurations.



NOTE: The USAF also has developed a Mobile Microwave Landing System (MMLS). MMLS components may be deployed in same configuration as a conventional MLS or the azimuth, elevation and DME transmitters may be collocated. MMLS approaches may only be flown by properly-equipped aircraft. MMLS operations are the same as the MLS unless otherwise noted in this manual or the aircraft tech order.

- **Displays.** MLS displays are virtually identical to the ILS. Both lateral and vertical MLS guidance may be displayed on conventional course deviation indicators or incorporated into multipurpose cockpit displays. Range information can be displayed by conventional DME indicator or incorporated into multipurpose displays.

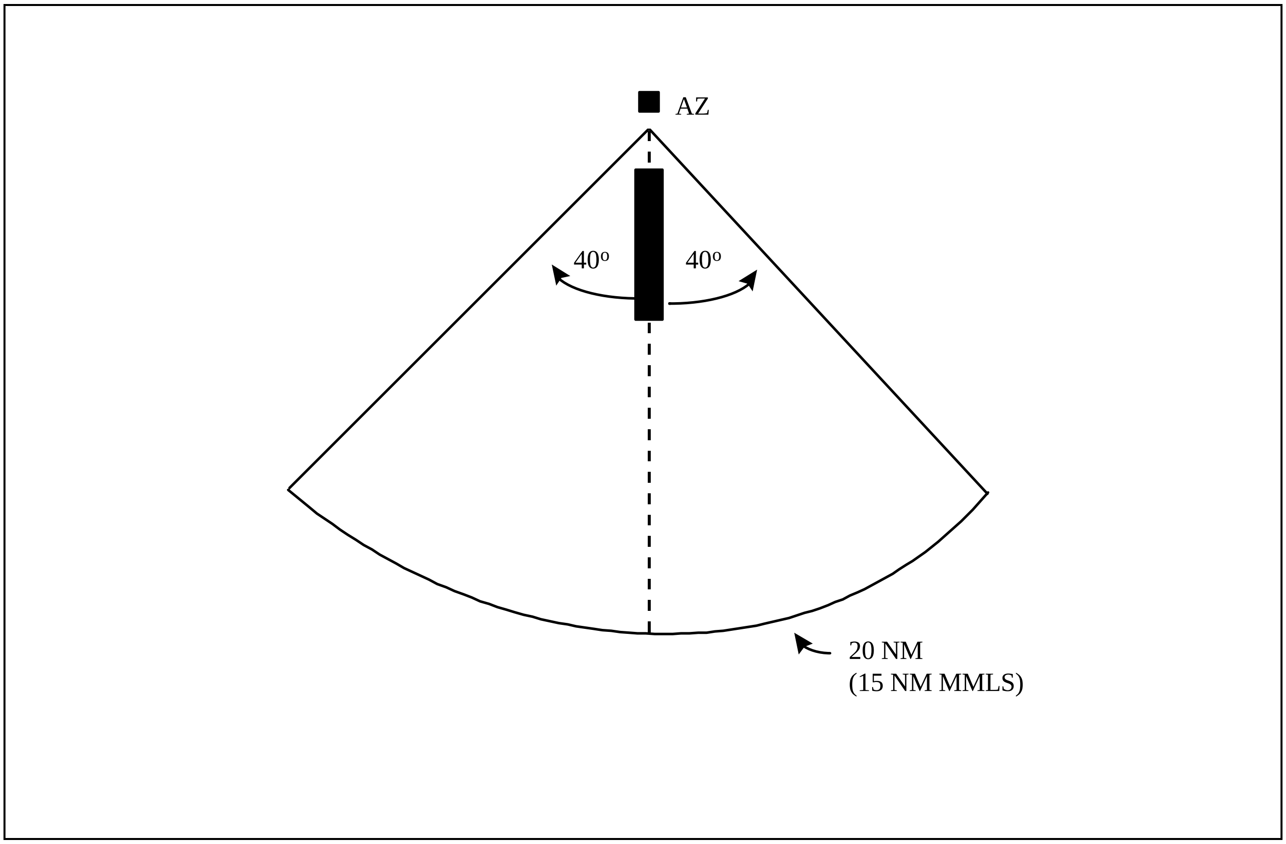
2.1.2. Approach Azimuth (AZ) Guidance.

2.1.2.1. Azimuth Guidance. In addition to providing azimuth navigation guidance, the azimuth station also transmits basic data concerning the operation of the landing system and advisory data on the performance level of the ground equipment.

2.1.2.2. Azimuth Coverage Area (Figure 2.2). The limits of the azimuth coverage area are:

- **Laterally.** Proportional coverage or clearance signal to at least ± 40° on either side of the runway.
- **In elevation.** From the horizon (0°) up to an angle of 15° and up to at least 20,000 feet.
- **In range.** To a distance of at least 20 NM (MMLS maximum range is 15 NM).

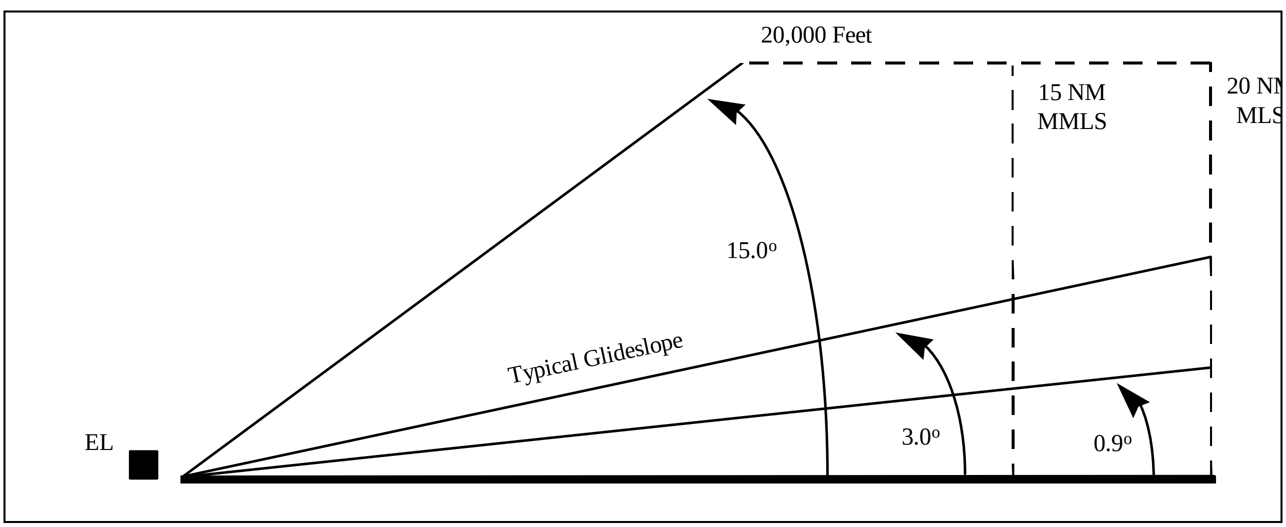
Figure 2.2. Typical Azimuth Coverage Area.



2.1.3. Elevation (EL) Guidance (Figure 2.3).

- **Elevation station.** The elevation station transmits its guidance signals on the same carrier frequency as the azimuth station. The single frequency is time-shared between angle and data function.
- **Coverage.** To a distance of at least 20 NM (MMLS maximum range is 15 NM).

Figure 2.3. Elevation Coverage Area.



2.1.4. MLS Precision Distance Measuring Equipment (DME/P). The MLS precision distance measuring equipment (DME/P) functions in the same way as the DME described in the TACAN section of this manual. DME/P accuracy within

7 NM of the station has been improved to be consistent with the accuracy provided by the MLS azimuth and elevation stations. The DME/P is an integral part of the MLS.

2.1.5. MLS Expansion Capabilities. The standard MLS configuration can be expanded by addition of one or more of the following functions:

- **Back Azimuth (BAZ).** To provide lateral guidance for missed approach and departure navigation. (MMLS will not support back azimuth)
- **Auxiliary Data Transmissions.** To provide additional data, including meteorological information, runway condition, and other supplementary information. This digitally transmitted data may be displayed on appropriately equipped aircraft.
- **Larger Coverage Area.**

2.1.6. MLS Characteristics.

- **Accuracy.** The MLS provides precision three-dimensional navigation guidance accurate enough for all approach and landing maneuvers.
- **Coverage.** Precise navigation accuracy is provided throughout the coverage volumes.
- **Environment.** The system has low susceptibility to interference from weather conditions and airport ground traffic.
- **Channels.** MLS has 200 discrete channels. Normally, Air Force aircraft will use only even-numbered MLS channels. Even-numbered channels are paired with X- and Y-band TACAN stations; odd-numbered channels are paired with W- and Z-band TACANs.
- **Identification.** MLS identification is via a four-letter system always beginning with the letter "M." The four-letter identifier is transmitted at least six times per minute by the approach azimuth (or back azimuth) ground equipment. Some aircraft installations do not include the audible identification feature; in this case, the MLS can be identified by observing the correct 4-letter identifier on the aircraft's avionics display.
- **Data.** The MLS transmits ground-air data messages associated with system operation including the MLS station identifier, glide path information, approach azimuth course, and AZ transmitter offset distance, if applicable.
- **Range Information.** Continuous range information is provided to an accuracy of approximately 100 feet (within 7 NM of the station) if the aircraft's avionics includes DME/P capability. The range information is compatible with existing DME and TACAN avionics; however, the accuracy is downgraded to approximately 600 feet if using a standard DME receiver.
- **Operational Flexibility.** The MLS can fulfill a variety of needs in the transition, approach, landing, missed approach and departure phases of flight. Some additional capabilities associated with MLS include curved and segmented approaches, selectable glideslope angles, accurate three-dimensional positioning of the aircraft in space, and the establishment of boundaries to ensure clearance from obstructions in the terminal area.

NOTE: While some of these capabilities are available to any MLS equipped aircraft, the more sophisticated capabilities, such as curved and segmented approaches, are dependent upon the capabilities of the aircraft's equipment. Refer to your aircraft flight manual for the specific capabilities of your MLS equipment.

2.2. Modes of Operation. There are two modes of operation for MLS approaches: automatic and manual.

- **Automatic Mode.** The automatic mode of operation is the default mode and the preferred method of operation. When flying an MLS approach using the automatic mode, the approach's published azimuth and glideslope information is transmitted to your aircraft's MLS receiver.
- **Manual Mode.** Some MLS receivers will also permit you to fly approaches in the manual mode. In the manual mode, you may change the azimuth and/or glideslope angle of the MLS approach.

WARNING: If operating in manual mode and the pilot selects a course and/or glideslope different from the published procedure, the published approach is no longer valid and the actual approach flown will no longer guarantee obstacle clearance.

2.3. Types of MLS Approaches. There are two types of MLS approaches: non-computed and computed. These approaches may be flown in the automatic mode (preferred) or the manual mode. Non-computed IAPs are identified by the absence of the word "COMP" in the approach title (for example, MLS RWY 07). Computed approaches include the word "COMP" in the approach title (for example, COMP MMLS RWY 35).

2.3.1. Non-Computed. When flying a non-computed MLS approach, the azimuth signal steers your aircraft to the azimuth antenna just as approaches to traditional NAVAIDs such as VOR or TACAN do. Consequently, it is important for you to know where the azimuth antenna is located on the airfield. Non-computed approaches should be flown using the default settings (AUTO and NON-COMP) of your MLS equipment.

- **Standard Installation.** In the most common MLS installation, the antenna is located along the runway centerline between 1,000 and 1,500 feet from the departure end of the runway. When flying a non-computed approach to this type of installation, your final approach will normally be lined up along the extended runway centerline.
- **Offset Installation.** In some installations, the azimuth antenna may be installed alongside the runway (offset). In this case, when flying a non-computed approach, the azimuth guidance will not steer your aircraft to the runway along the extended runway centerline. Refer to Figure 2.4 for an example of a non-computed approach to a split site MLS ground configuration. In this particular configuration, the azimuth is rotated so that the azimuth signal guides your aircraft to the azimuth antenna along a course that is not parallel to the runway centerline. It is important to realize that MLS approaches can have final approach courses that are not parallel to the runway centerline. Review the approach plate carefully for notes to that effect and for the arrow leading up to the aerodrome sketch to determine where to look for the runway at the missed approach point.

WARNING: If you are flying a non-computed MLS approach (i.e., an approach named "MLS RWY 23" or "MMLS RWY 23," and you select the "COMPUTED" approach mode on your MLS equipment, the published approach is no longer valid and the actual approach flown will no longer guarantee obstacle clearance. The only time the "COMPUTED" mode should be selected is when the approach to be flown is a computed approach (i.e., an approach named "COMP MMLS RWY 23.")

2.3.2. Computed (COMP). A computed MLS approach steers your aircraft to the runway along a course aligned with the extended runway centerline regardless of the location of the ground transmitters. Computed approaches can only be flown by aircraft having MLS receivers capable of using computed approach guidance. Using slant-range DME, the azimuth transmitter's known location and offset distance from the runway centerline, the MLS receiver-processor computes an offset approach path which will steer the aircraft to the runway along the extended runway centerline. Computed IAPs are identified by the word "COMP" in the approach title (for example, refer to the "COMP MMLS RWY 09" at Tuzla shown in Figure 2.4.). Computed approaches should be flown using the AUTO and COMP settings of your MLS equipment.

2.3.3. Example. In this example, refer to the MLS RWY 34 approach at Fayetteville, AR (Figure 2.5).

2.3.3.1. Unique Installation. There are a few unique features associated with this approach. First, the MLS azimuth transmitter is offset, not on runway centerline as you would normally expect at a civil field. The MLS azimuth antenna is located right of the runway about two-thirds of the way down. Second, the final approach azimuth diverges 5.5° from the runway centerline due to high terrain along the extended runway centerline. Finally, the MLS glideslope is steeper than normal (3.5°).

2.3.3.2. Flying the Fayetteville Approach. To fly this approach, tune the Fayetteville MLS frequency (Channel 642) on your aircraft's equipment. Identify the MLS station (M-FZD) by listening to the audible ident or by observing the MFZD identifier on your aircraft's avionics display. Make sure the published front course is set in your HSI so the navigation display will be directional. The MLS receiver should be in the automatic and non-computed mode (because "COMP" is not in the approach title). Your MLS equipment should automatically indicate the approach azimuth (349°) and glideslope (3.5°). The final step is to select MLS information for your flight director.

NOTE: Because the MLS azimuth transmitter is not on runway centerline, it transmits an azimuth offset distance data word—a data word normally associated with computed approaches. Some aircraft's MLS equipment may display a message notifying the pilot of receipt of the offset azimuth data word when non-computed mode is selected. This message alerts the pilot that an unexpected mode is selected. The pilot should confirm proper mode selection by looking at the title of the approach. In the case of "MLS RWY 34" at Fayetteville, AR, the absence of the word "COMP" in the approach title denotes it is a non-computed approach.

Figure 2.4. Computed MMLS Approach (para 2.3.2)

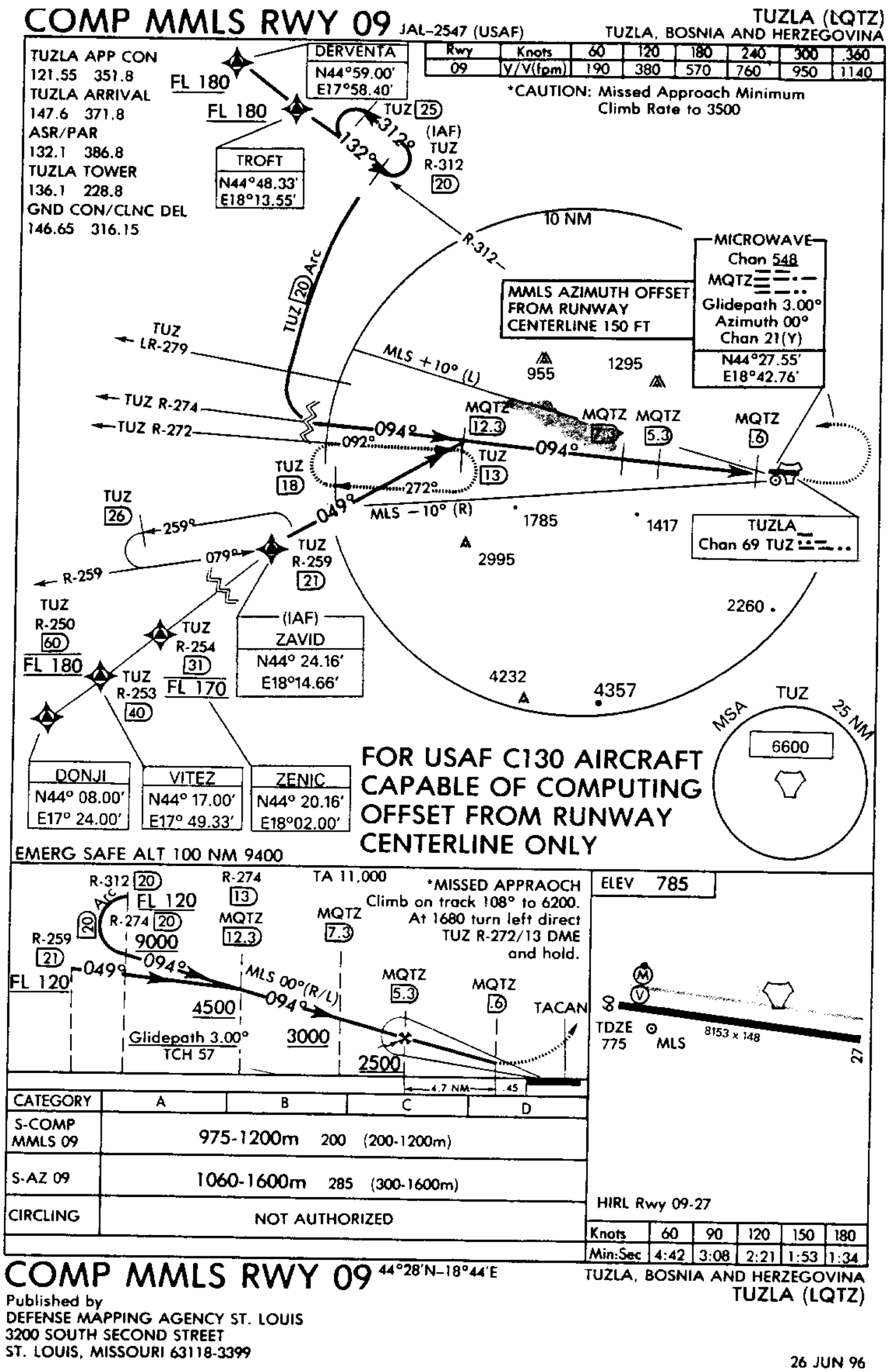
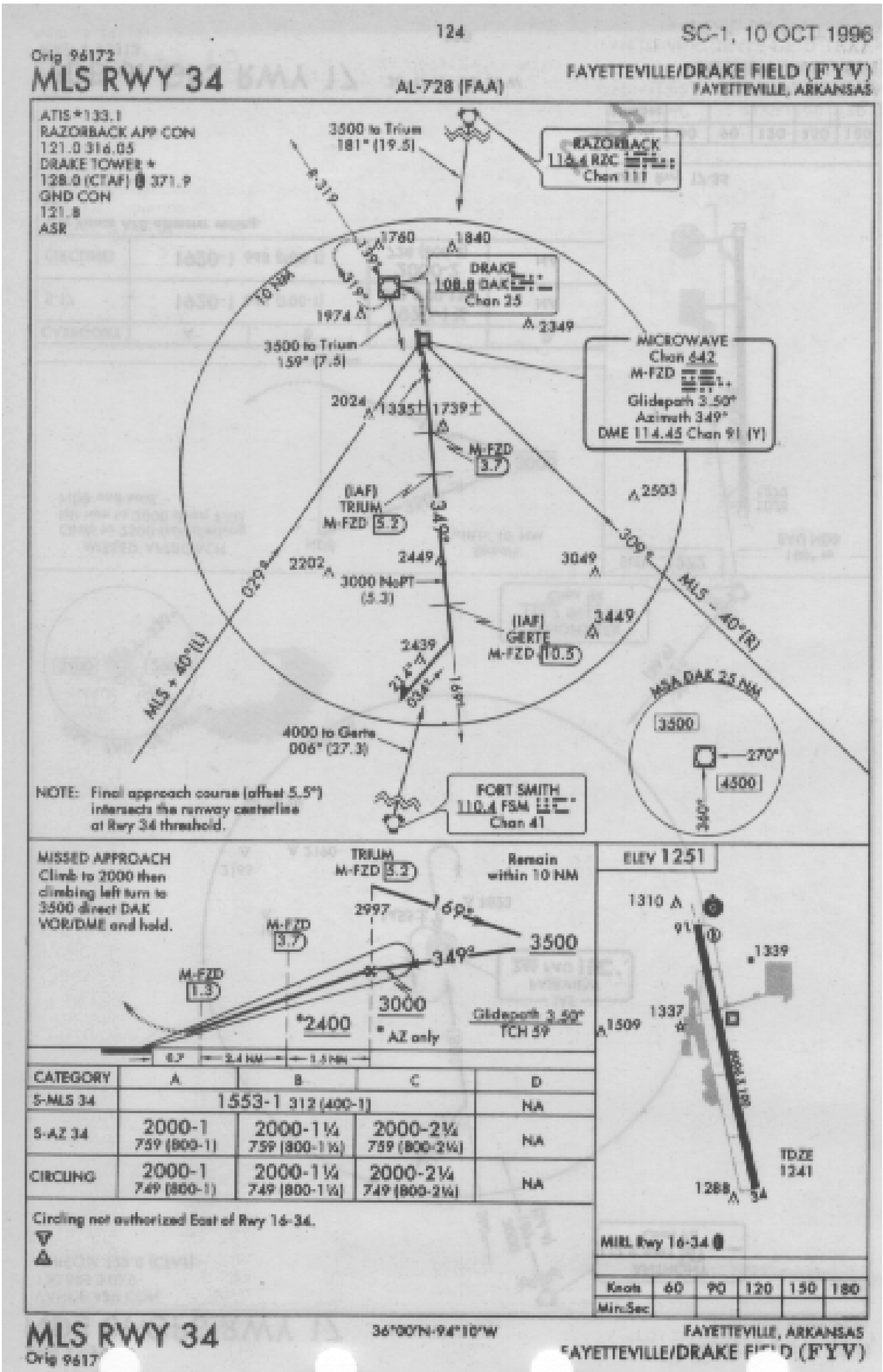


Figure 2.5. MLS RWY 34 Approach at Fayetteville, AR.



2.3.3.3. Computed vs. Non-Computed Mode. To fly the MLS RWY 34 approach at Fayetteville, the MLS receiver should be in the non-computed mode of operation. The non-computed mode is the default setting of the MLS receiver. When the MLS RWY 34 is flown in the non-computed mode (as it is intended to be flown), the aircraft is steered to the airport along a final approach course that diverges 5.5° from runway centerline (Figure 2.6). If the pilot switches the MLS receiver to the computed mode, the aircraft will be steered to the runway along the extended runway centerline which is not what the TERPs specialist had in mind when the approach was designed (Figure 2.7).

WARNING: If you are flying a non-computed approach (i.e., an approach named "MLS RWY 23" or "MMLS RWY 23," and you select the "COMPUTED" approach mode on your MLS equipment, the published approach is no longer valid and the actual approach flown will no longer guarantee obstacle clearance. The only time the "COMPUTED" mode should be selected is when the approach to be flown is a computed approach (i.e., an approach named "COMP MMLS RWY 23.")

2.3.3.4. Manual vs. Automatic Mode. Likewise, if you switch to manual mode and change either the approach azimuth or glideslope, the IAP you are using is no longer valid.

- **Elevation Angle.** An elevation angle less than what the approach was designed for may not give you obstacle clearance, and an elevation higher than the published angle mandates higher approach minima.
- **Approach Azimuth.** If you change the published approach azimuth in manual mode, your aircraft will be steered to the runway along a different course than published which may take you outside of the airspace the TERPs specialist has protected for you.

WARNING: When flying an MLS approach, if operating in manual mode and the pilot selects an azimuth different from the published procedure, the published approach is no longer valid and the actual approach flown will no longer guarantee obstacle clearance. Follow MAJCOM directives regarding flying MLS approaches in the manual mode.

Figure 2.6. Non-Computed Mode.

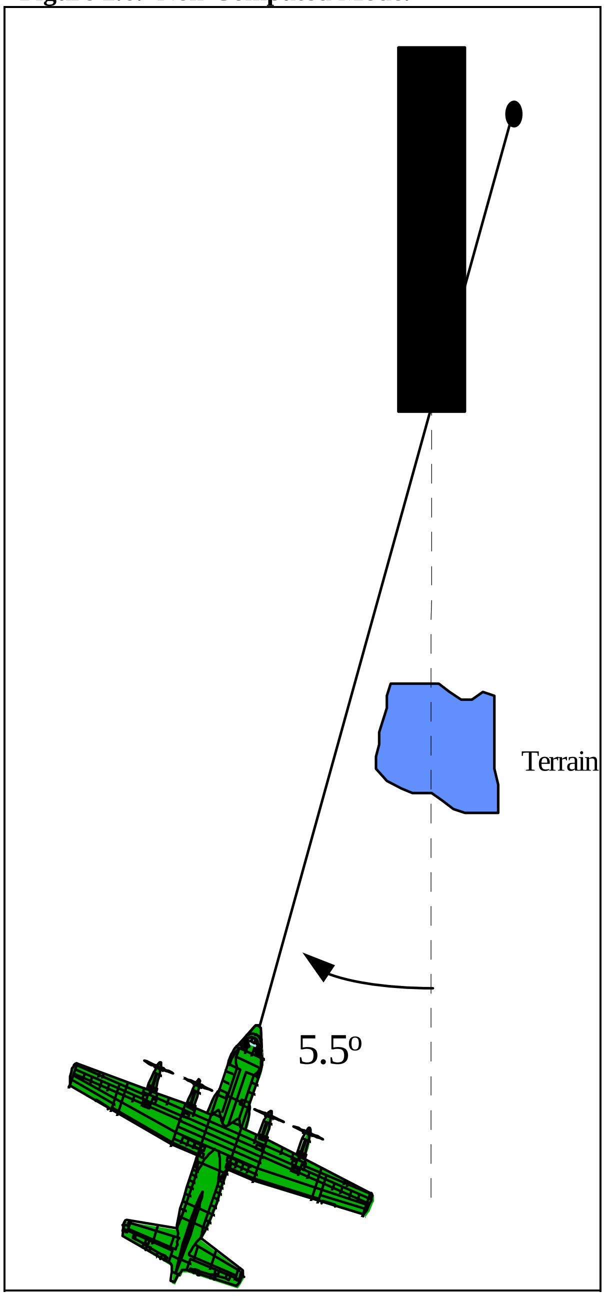
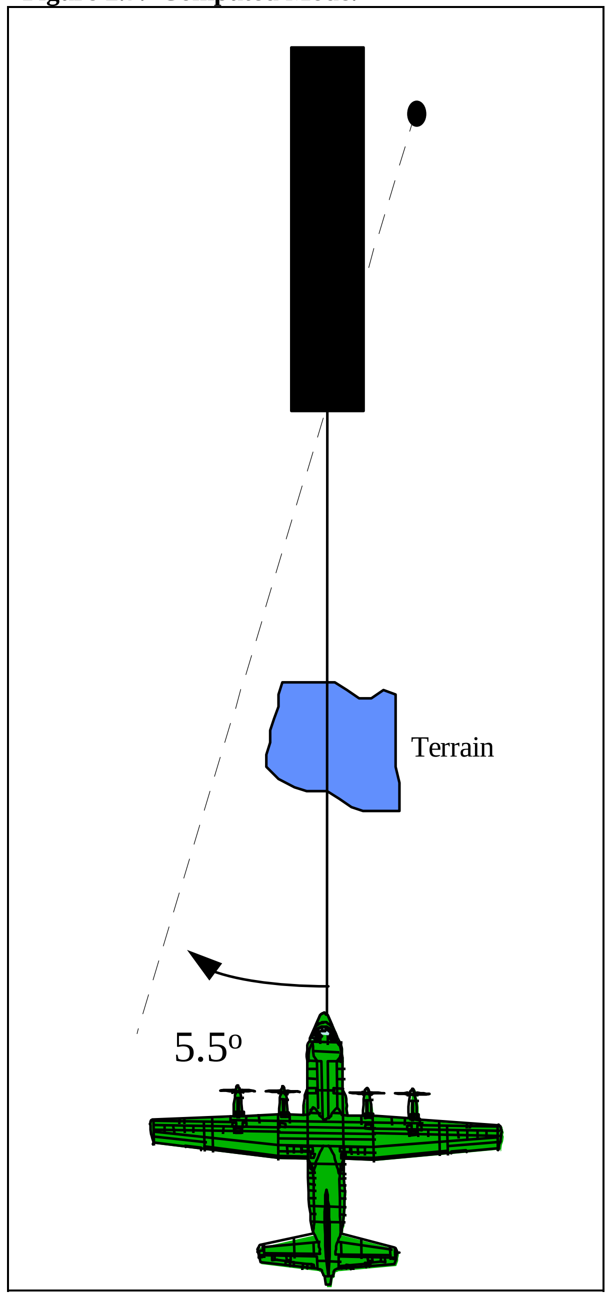


Figure 2.7. Computed Mode.



2.4. Flying MLS Approaches. Just as an ILS approach usually contains a precision (ILS) and a non-precision (localizer) approach, MLS procedures will normally include a precision (MLS) and a non-precision (azimuth-only) approach.

2.4.1. Precision (MLS).

2.4.1.1. Transition to the MLS Course. Transition to the MLS final approach course by using either radar vectors or a published instrument approach procedure.

- **Tune.** Tune the MLS as soon as practicable during the transition to final and monitor the MLS identifier during the entire approach. The MLS is identified by a four-letter identifier always beginning with the letter "M." The four-letter ident is transmitted at least six times per minute by the approach azimuth (or back azimuth) ground equipment. Some aircraft installations do not include the audible identification feature; in this case, the MLS can be identified by observing the correct 4-letter identifier on the aircraft's avionics display.
- **Azimuth and Glideslope Selection.** The MLS receiver will automatically select the appropriate azimuth and glideslope as well as tune the TACAN for distance information. When operating in the manual mode, you may change the published azimuth and glideslope angle.

WARNING: If operating in manual mode and the pilot selects a course and/or glideslope different from the published procedure, the published approach is no longer valid and the actual approach flown will no longer guarantee obstacle clearance.

- **Orientation.** Use appropriate navigation facilities (for example, VOR or NDB) to remain position-oriented during the approach.
- **Using a Flight Director.** When using a flight director system, the switches should be positioned in accordance with instructions in the aircraft flight manual for the intercept and final approach modes of operation.

NOTE: MMLS approaches may only be flown by aircraft with the proper equipment. All other procedures to fly the approach will be the same as for conventional MLS.

WARNING: If you are flying a non-computed approach (i.e., an approach named "MLS RWY 23" or "MMLS RWY 23," and you select the "COMPUTED" approach mode on your MLS equipment, the published approach is no longer valid and the actual approach flown will no longer guarantee obstacle clearance. The only time the "COMPUTED" mode should be selected is when the approach to be flown is a computed approach (i.e., an approach named "COMP MMLS RWY 23.")

2.4.1.2. Accomplish the Approach.
2.4.1.2.1. Interception. Once the MLS course is intercepted, reduce heading corrections as the aircraft continues inbound. Heading changes made in increments of 5° or less will usually result in more precise course control.
2.4.1.2.2. Descent. When on the MLS course, maintain glideslope intercept altitude (published or assigned) until intercepting the glideslope. Published glideslope intercept altitudes may be minimum, maximum, mandatory, or recommended altitudes and are identified by a lightning bolt (). When the glideslope intercept altitude is a recommended altitude, you must only comply with other IAP altitudes (FAF altitude for example) until established on the glideslope. Do not descend below a descent restrictive altitude (minimum or mandatory, not recommended) if the CDI indicates full scale deflection.
2.4.1.2.3. Glideslope Indicator. Prepare to intercept the glideslope as the glideslope indicator (GSI) moves downward from its upper limits. Determine the approximate rate of descent to maintain the glideslope. The vertical velocity required to maintain this angle of descent will be dependent upon the aircraft groundspeed and the glideslope angle. Slightly before the GSI reaches the center position, coordinate pitch and power control adjustments to establish the desired rate of descent.

- **Pitch Adjustments.** Pitch adjustments made in increments of 2° or less will usually result in more precise glideslope control. As the approach progresses, smaller pitch and bank corrections are required for a given CDI/GSI deviation.
- **Over-Controlling.** During the latter part of the approach, pitch changes of 1° and heading corrections of 5° or less will prevent over-controlling.
- **Steering Commands.** If using pitch and bank steering commands supplied by a flight director system, monitor basic flight data (raw data) and aircraft performance instruments to ensure the desired flight path is being flown and aircraft performance is within acceptable limits. A common and dangerous error when flying an MLS approach using a flight director is to concentrate only on the steering bars and ignore other flight path and aircraft performance instruments. Failure of the flight director computer (steering bars) may NOT always be accompanied by the appearance of warning flags. Steering commands must be correlated with flight path (CDI and GSI) and aircraft performance instruments.

2.4.1.2.4. Crosscheck. Maintain a complete instrument crosscheck throughout the approach, with increased emphasis on the altimeter during the latter part (DH is determined by the barometric altimeter). Establish a systematic scan for the runway environment prior to reaching DH. At DH, if visual reference with the runway environment is established, continue the approach to landing using flight instruments to complement the visual reference.

WARNING: The MLS approach must be discontinued if the course becomes unreliable, or any time full scale deflection of the CDI occurs on final approach. Do not descend below azimuth-only minimums if the aircraft is more than one dot (half scale) below or two dots (full scale) above the glideslope. If the glideslope is recaptured to within the above tolerances, descent may be continued to DH.

NOTE: If making an autopilot coupled approach or landing, follow the aircraft flight manual procedures. When autopilot coupled operations are to be conducted, advise the ATC approach controller as soon as practical, but not later than the FAF. This will allow time for the appropriate critical area to be cleared or an advisory issued.

2.4.2. Non-Precision (Azimuth-Only).
2.4.2.1. Final Approach.

- **Final Approach Segment.** The final approach segment starts at the final approach fix (FAF) and ends at the missed approach point (MAP). The optimum length of the final approach is 5 miles; the maximum length is 10 miles.
- **Azimuth-Only MLS signal.** The azimuth signal has a usable range of at least 20 miles (15 NM for MMLS) within ± 40° of the course centerline unless otherwise stated on the IAP. If operating in the automatic mode (the preferred mode), the receiver will automatically select the appropriate azimuth as well as tune the TACAN for distance information. If operating in manual mode, you must manually set the desired azimuth.

NOTE: MMLS azimuth-only approaches may only be flown by aircraft with the proper equipment.

WARNING:

1. When flying an MLS azimuth-only approach, if operating in manual mode and the pilot selects an azimuth different from the published procedure, the published approach is no longer valid and the actual approach flown will no longer guarantee obstacle clearance.
2. If you are flying a non-computed MLS approach (i.e., an approach named "MLS RWY 23" or "MMLS RWY 23," and you select the "COMPUTED" approach mode on your MLS equipment, the published approach is no longer valid and the actual approach flown will no longer guarantee obstacle clearance. The only time the "COMPUTED" mode should be selected is when the approach to be flown is a computed approach (i.e., an approach named "COMP MMLS RWY 23.")

2.4.2.2. Flying the Approach.

- **Descent.** Avoid rapid descent requirements on final by crossing the FAF at the published altitude.

CAUTION: Non-precision approach procedures published in conjunction with an MLS do not always clearly depict the FAF crossing altitude. Careful review of the IAP using the following guidance is required. The minimum altitude to be maintained until crossing the fix following the glideslope intercept point (normally the FAF will be the next fix) is the published glideslope intercept altitude, altitude published at that fix, or ATC assigned altitude. For most non-precision approaches, the glideslope intercept altitude will be the minimum FAF crossing altitude.

- **Timing.** Timing is required when the final approach does not terminate at a published fix, as is usually the case with VOR, NDB, and localizer. Begin timing when passing the FAF or the starting point designated in the timing block of the approach plate. This point is usually the FAF, but it may be a fix not co-located with the FAF such as a LOM, NDB, crossing radial, DME fix or outer marker. Time and distance tables on the approach chart are based on groundspeed; therefore, the existing wind and TAS must be considered to accurately time the final approach. If timing is published on the approach plate, then timing can also be valuable as a backup in the event of DME loss or other problems that might preclude determination of the MAP. If timing is not published, timing is not authorized as a means of identifying the missed approach point.

NOTE:

1. If timing is not specifically depicted on the instrument approach procedure, timing is not authorized as a means of identifying the missed approach point (MAP).
2. Timing is the least precise method of identifying the missed approach point; therefore, when the use of timing is not authorized for a particular approach because of TERPs considerations, timing information will not be published.
3. The middle marker may be an accurate means of identifying the MAP on certain localizer approaches provided it is coincident with the published localizer MAP. To determine the location of the MAP, compare the distance from the FAF to MAP adjacent to the timing block. It may not be the same point as depicted in the profile view. However, if the MM is received while executing such an approach, and other indications (DME and/or timing) agree, you may consider yourself at the MAP and take appropriate action.

- **Turns.** If a turn is required over the FAF, turn immediately and intercept the final approach course to ensure that obstruction clearance airspace is not exceeded.
- **Minimum Descent Altitude (MDA).** Do not descend to the minimum descent altitude (MDA) or step down fix altitude until passing the FAF (if published).
- **Visual Descent Point (VDP).** Arrive at MDA (MDA is determined by the barometric altimeter) with enough time and distance remaining to identify runway environment and depart MDA from a normal visual descent point to touchdown at a rate normally used for a visual approach in your aircraft.

- **Runway environment.** Descent below MDA is not authorized until sufficient visual reference with the runway environment has been established and the aircraft is in a position to execute a safe landing. Thorough preflight planning will aid you in locating the runway environment.

CAUTION: Depending on the location of the MAP, the descent from the MDA (once the runway environment is in sight) often will have to be initiated prior to reaching the MAP in order to execute a normal (approximately 3°) descent to landing.

- **Alignment.** Be aware that the final approach course on a non-radar final may vary from the runway heading as much as 30° and still be published as a straight-in approach.

NOTE: When fixes on the IAP are depicted as defined by radar, only ground-based radar, such as airport surveillance, precision, or air route surveillance radar, may be used to position the aircraft.

2.5. Inoperative System Components.

- **Azimuth Failure.** If the azimuth transmitter is inoperative, no approach is authorized.
- **Elevation Failure.** If the elevation transmitter is inoperative, only the non-precision (azimuth-only) approach is authorized.
- **DME Failure.** For collocated facilities, if the MLS DME transmitter is inoperative, computed approaches are not permitted.

Chapter 3

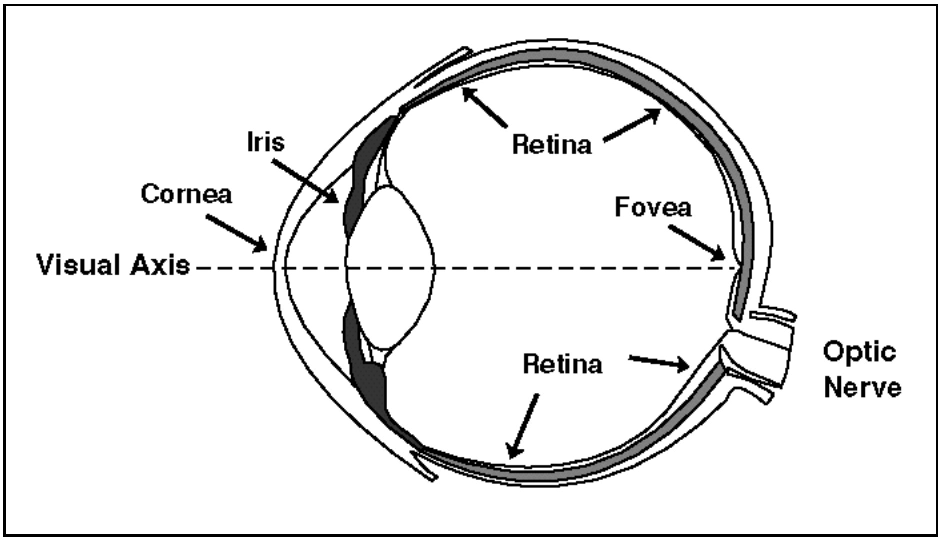
NIGHT VISION DEVICES (NVDS)

3.1. Introduction. Vision is arguably the most important sense used in flight. During day or night, vision is the sense that allows crewmembers to remain aware of their position in space. The brain rapidly interprets visual cues during daylight. As we transition to night operations, visual acuity decreases as the illumination level decreases. To compensate for this and improve our ability to operate in the night environment, the Air Force has begun wide-spread use of night vision devices (NVDs). To fully exploit the night, you must first understand principles of night vision. Through these principles, you will come to recognize that the Air Force's most commonly used NVD, night vision goggles (NVGs), don't turn night into day. NVGs allow you to operate more safely in the night low-level environment, but you must remember that they are only an aid and cannot replace proper planning and good judgment.

3.2. The Human Visual System.

3.2.1. Anatomy and Physiology of the Eye. Understanding the anatomy and physiology of the eye and how it affects NVG utilization will help you better appreciate the eye/NVG interface.

Figure 3.1. The Visual Process (para 3.2.1.1).



3.2.1.1. The Visual Process (Figure 3.1). Energy—in the form of light—enters the eye through the cornea, passes through the pupil to the lens, and is focused onto the retina. The energy causes chemical changes within photosensitive cells (cones and rods) in the retina. These chemical changes result in electrical impulses that are transmitted by the optic nerve to the brain. The brain then interprets the impulses and creates a mental image.

- **Cone Cells.** Cone cells are principally used for day vision, and are mostly found in the fovea--located in the central part of the retina. They require high levels of energy (light) to function, give the best resolution, and provide for color vision. Moving outwards from the fovea, cone cells become less dense.
- **Rod Cells.** Rod cells are used for night or low-light vision, and are located mostly outside the fovea. As the light level decreases, rod cells begin to handle more of the visual task. Because they use a photosensitive chemical different than cone cells, the resulting image is perceived as varying shades of gray. Since there are few rod cells in the fovea, and cone cells do not function during low light levels, a "blindspot" is created at the foveal location. That is why it is necessary to view objects, such as light sources, slightly off center during extreme low light conditions.

3.2.1.2. Components of Vision. There are two components of the visual system, focal (fovea) vision and ambient (peripheral) vision. Focal vision is primarily responsible for object recognition, and ambient vision is primarily responsible for spatial orientation.

- **Focal Vision.** Focal vision is limited to the central two degrees of vision (i.e., the fovea) and is primarily a conscious function. Focal vision allows one to see clearly in order to recognize objects and read displays. However, since it requires conscious thought, it is a relatively slow process. Focal vision is not primarily involved with orienting oneself in the environment, but can be used to acquire visual information about orientation.
- **Ambient Vision.** Ambient vision is often referred to as peripheral vision. It is a subconscious function independent of focal vision whose primary role is to orient an individual in the environment. For example, one can fully occupy focal vision by reading (a conscious action), while simultaneously obtaining sufficient orientation cues with peripheral vision to walk (a subconscious function). The same can happen when flying an aircraft and performing a task such as interpreting radar contact information on a HUD. Focal vision is used to consciously decipher task-oriented information while peripheral information is subconsciously used to maintain spatial orientation.

3.2.1.3. Dark adaptation. Dark adaptation is the process by which your eyes increase their sensitivity to lower levels of illumination. Rod cells require the generation of a chemical called rhodopsin (visual purple) in order for this process to occur. The degree of dark adaptation increases as the amount of visual purple in the rods increase through the biochemical reactions. People adapt to the dark in varying degrees and at different rates. For most people, the sensitivity of the eye increases roughly 10,000-fold during the first 30 minutes, with little increase after that time.

- One of the variables that determines the time for dark adaptation to take place is the length of exposure to bright light. If you have not been exposed to long periods of bright light, either through the use of sunglasses or spending the day indoors, you will likely dark adapt normally. On the other hand, if you are exposed to a large amount of unfiltered white light during the day, dark adaptation will take much longer. In extreme cases (snow-blindness or very reflective sand and water conditions), dark adaptation may not be possible for hours or even days. Under normal circumstances, however, complete dark adaptation is reached in approximately 30 to 45 minutes. If the dark-adapted eye is then exposed to a bright light, the sensitivity of that eye is temporarily impaired, with the amount of impairment depending on the intensity and duration of the exposure. Brief exposure to a bright light source can have minimal effect upon night vision because the pulses of energy are of such short duration. However, exposure to a bright light source (e.g., lightning or flares) for longer than one second can seriously impair your night vision. Depending on the intensity and duration of exposure, recovery to a previous level of dark adaptation can take anywhere between 5 and 45 minutes.

- The NVG image is perceived in shades of green and is not very bright, which means that you are using both cone cells (color vision) and rod cells (low light vision) to see the image. When using both types of cells, you are in an intermediate state of dark adaptation (described more in-depth later). Once reaching this intermediate state and after discontinuing goggle use, it will take you approximately 5-8 minutes to regain full dark adaptation. Consequently, NVG use should be discontinued for a period of time prior to your requiring full dark adaptation (e.g., landing).
- If you are not fully dark adapted prior to beginning goggle operations, you will continue to dark adapt while using them.

3.2.1.4. Types of Vision. Vision is divided into three categories based on the amount of ambient illumination available to the eye.

- **Photopic Vision.** Photopic vision defines the visual capability during daylight hours or when a high level of artificial illumination exists, normally 20/20 or better. Under these conditions, visual perception is achieved primarily by the cone cells. Due to the high light condition, rod cells are bleached out and become less effective. Two key characteristics of photopic vision are sharp images and the ability to distinguish colors. Additionally, objects are viewed primarily with focal (foveal) vision, but can be detected with ambient (peripheral) vision (outside the foveal area).
- **Scotopic Vision.** Scotopic vision defines visual capability when there is not enough light available to stimulate the cones in the fovea--the site of your best resolution. The result is poor scene resolution, on the order of 20/200 or less, and a corresponding loss of color perception. Because of the blind spot created at the site of the fovea, scanning is required to locate objects, and offset eye positions are required to keep them in sight. Otherwise, the image of the object may fade after a few seconds.
- **Mesopic Vision.** Mesopic vision defines the visual capability in the intermediate stage between photopic and scotopic vision that is normally experienced at dawn, dusk, and during other periods of mid-light levels (e.g., NVG operations). Mesopic vision is achieved by using a combination of both rod and cone cells.

3.2.2. Spatial Orientation. Spatial orientation, or the ability to move and orient oneself in respect to the earth's surface, requires inputs from the two components of the visual system. Those two components, as described earlier, are focal vision, which is primarily responsible for object recognition, and ambient vision, which is primarily responsible for spatial orientation. The following information is a shortened presentation of the expanded spatial disorientation section in AFMAN 11-217, Vol. 1. For a more detailed explanation, please refer to that section.

3.2.2.1. Spatial Orientation and NVGs. The use of NVGs allows aircrews to see objects at night that could not be seen during unaided operations. However, you must use your focal vision to interpret the NVG image. Since spatial orientation at night or in weather requires the use of focal vision to process data from instrument displays, more time and effort is required to maintain spatial orientation during NVG operations than during daytime operations. Additionally, due to the goggles reduced field of view (FOV) and the lack of visual cues in the periphery, more reliance is placed on focal vision. This reliance on focal vision can increase the aviator's workload and susceptibility to spatial disorientation.

3.2.2.2. Spatial Disorientation. Anything placing a higher demand upon or degrading focal vision will increase the risk of spatial disorientation. The following factors adversely affect focal vision and therefore may contribute to the onset of spatial disorientation.

- **Degraded Visual Environment.** Night is a degraded visual environment when compared to daylight, and the image provided by NVGs is inferior when compared to a person's normal day vision. Additionally, anything that degrades the NVG image (decreased illumination levels or atmospheric obscurants) will further increase the risk of spatial disorientation.
- **High Task Loading/Task Saturation.** Flying with the aid of NVGs requires complex conscious processing of data from various instruments and displays. This increased demand on focal vision must compete with the usual tasking of navigation, terrain masking, threat avoidance, etc. High task loading can saturate the conscious process and increase the risk of spatial disorientation.

3.3. The Night Environment.

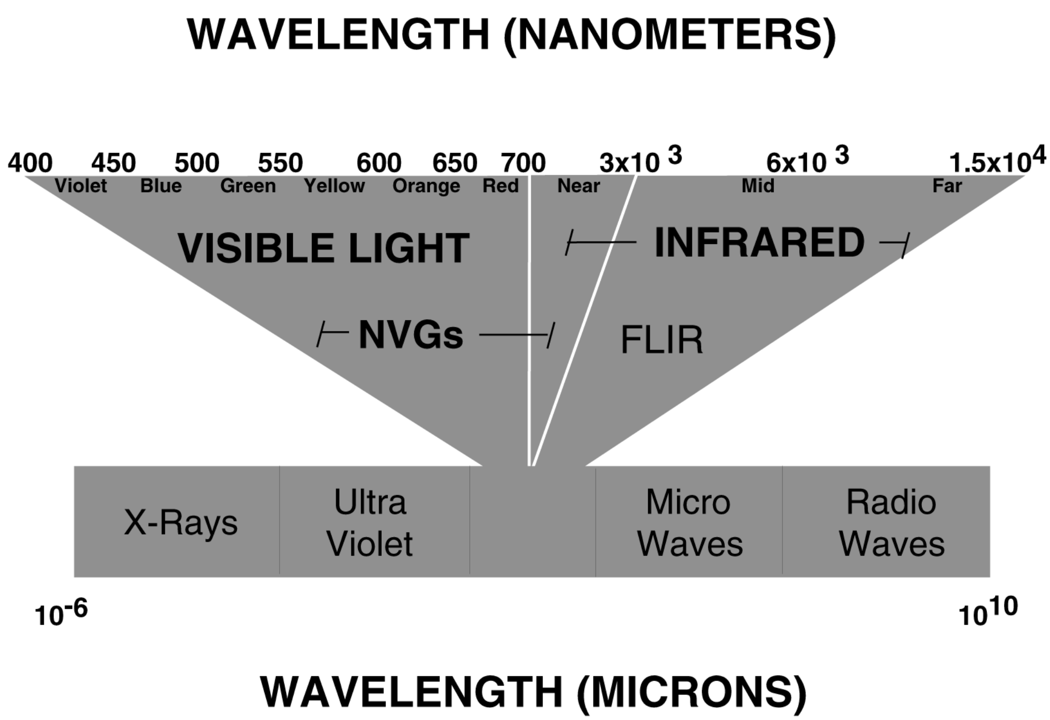
3.3.1. Properties of Energy.

3.3.1.1. Electromagnetic Spectrum (Figure 3.2). Both the light that stimulates the unaided eye and the energy intensified by NVGs are represented by areas on the electromagnetic spectrum. All types of radiant energy are contained in this spectrum, from cosmic rays to radio waves. Since visible and infrared (IR) energy are both forms of radiant energy, they are located in the spectrum relative to their respective wavelengths. The portion of the electromagnetic spectrum that includes both visible and IR energy has been expanded to show more detail. The human eye and all NVDs are sensitive to different wavelengths in the spectrum, and those wavelengths are expressed in nanometers (nm). The human eye is sensitive to the visible spectrum (approximately 400 to 700 nm), which progresses from violet to blue, green, yellow, orange, then red. However, since a substantial amount of near-IR energy (approximately 700 nm to 900 nm) is present in the night sky, NVGs were designed to be sensitive to both visible and near-IR wavelengths. Thermal imaging systems, such as forward looking infrared (FLIR) devices, are sensitive to energy in the mid- and far-IR regions.

3.3.1.2. Terms. The following terms are used to describe properties of light:

- **Illuminance.** Illuminance (illumination) refers to the amount of light which strikes an object or surface at some distance from the source. An example is the amount of ambient light which strikes the ground from the moon.
- **Luminance.** Luminance refers to the amount of light reflected from a surface. An example is moonlight which is reflected from the terrain.
- **Albedo.** Albedo is the ratio between illuminance and luminance. Each surface has a different albedo--so while illumination from a light source may remain constant, luminance (reflectivity) from different terrain features or objects will vary. The light source provides illumination, or illuminance, but what our eyes see, and what NVGs intensify, is the energy reflected from objects and terrain, or luminance.

Figure 3.2. The Electromagnetic Spectrum (para 3.3.1.1).



- **Contrast.** Contrast is a measure of the luminance difference between two or more surfaces. In the night terrain environment, contrast is dependent upon differing albedo values for each type of terrain surface.
- **Shadows.** Shadows are cast by every object or surface if there is sufficient vertical contour and a light source (e.g., the moon) off axis from that surface. The direction in which the shadow is cast depends on the position of the light source, while the length of the shadow depends on the angle of the light source and the height of the object.
- **Nanometer.** The nanometer (nm) is a measurement of the wavelength of radiant energy at meters.

3.3.2. Sources of Illumination. Many natural and artificial sources of energy combine to illuminate the night environment. Natural sources include the moon, stars, solar light and other atmospheric reactions, while artificial sources include city lights, fires, weapons, searchlights and flares.

3.3.2.1. Moon. When present, the moon is the primary source of natural illumination in the night sky. The amount of moon illumination reaching the earth's surface is dependent on moon elevation above the horizon (moon angle) and the lunar phase.

- **Moon angle.** One of the factors that determines how much of the moon's illumination reaches the surface of the earth is the moon's angle relative to the horizon. Illumination from the moon is greatest when the moon is at its highest point (zenith) and at its lowest when the moon is just above the horizon. This effect is caused by absorption of energy as it travels through the atmosphere; at low moon angles there is more atmosphere for the energy to penetrate and hence more energy absorption occurs. Particulates in the atmosphere (e.g., rain, fog, dust) will also increase this absorptive effect. An additional problem associated with a low angle moon concerns the adverse effect it has on the NVG image. The bright light source (moon) will degrade the image making it difficult to see terrain detail such as ridgelines. In fact, flying towards a low angle moon results in problems similar to those experienced when flying towards a low angle sun. All these factors should be considered during mission planning.
- **Phases of the Moon.** Illumination is also affected by the phases of the moon. There are four distinct phases in the lunar cycle: new moon, first quarter, full moon and third quarter. For a period of time during the new moon phase, the moon face is completely in the earth's shadow (no apparent disk) and is not visible. However, this phase, which lasts about 8 days, also includes periods when approximately one quarter of the moon's surface is illuminated. A relatively low light level is characteristic of the new moon phase. Following the new moon phase is the first quarter (waxing) moon phase. One quarter to three quarters of the moon disk is visible during this phase, which lasts approximately 7 days, and good illumination is provided. The full moon phase covers the period when more than three quarters of the moon disk is visible and lasts approximately 8 days. The third quarter (waning) moon is the last phase and lasts about 7 days. It covers the time period when three quarters to one quarter moon disk illumination is present. Good illumination is provided during this phase, though slightly less than during the first quarter due to the type of lunar surface (mountainous) being illuminated by the sun. The entire cycle is repeated each "lunar month," which lasts approximately 29 days.
- **Shadows.** Another characteristic of the changing moon position is shadowing. Moonlight creates shadows during nighttime just as sunlight does during the day. However, understanding what you can not see in nighttime shadows is critical to NVG operations. Since they contain little or no energy (and some energy must be present for the NVGs to provide an image), shadows can completely hide obstructions such as ridgelines or towers, and may make it difficult to detect waypoints, targets, LZs, DZs, etc. The term foreshadowing refers to a particular shadowing situation in which near objects may be masked by the shadow created by a distant, higher object. Any of these effects can be a serious threat during low level flight.

3.3.2.2. Stars. The stars provide about 20 percent of the night sky illuminance on a moonless night. They contribute some visible light, but most of their contribution is in the form of near-IR energy. This means the majority of the energy is invisible to the human eye but is within the response range of NVG image intensifiers.

3.3.2.3. Solar Light. Skyglow is ambient light from the sun that can adversely affect NVG operations up to 11/2 hours after sunset and 1/2 hour prior to sunrise, depending on latitude and time of year. For example, in Alaska skyglow will have a prolonged effect during the time of year when the sun does not travel far below the horizon. Skyglow will affect the gain of the goggle and thus reduce image quality. The effect is similar to flying into a sunset and results in the loss of visual cues when looking either west (sunset) or east (sunrise). Mission planning should take skyglow and its effects into consideration.

3.3.2.4. Other Background Illumination. The greater portion (approximately 40 percent) of energy in the night sky originates in the upper atmosphere and is produced by a chemical reaction (ionization) processes. Other minor sources of night illumination are the aurora and zodiacal light caused by the scattering of sunlight from interplanetary particulate matter.

3.3.2.5. Artificial Sources. Lights from cities, industrial sites, and fires are also small sources of illumination. Light from weapon flashes, flares, and explosions can also adversely affect NVG performance, but the effects are usually short lived due to the nature of the source (e.g., short 20mm/30mm bursts). In this case, the goggle image would return to normal as soon as the offending light source disappears.

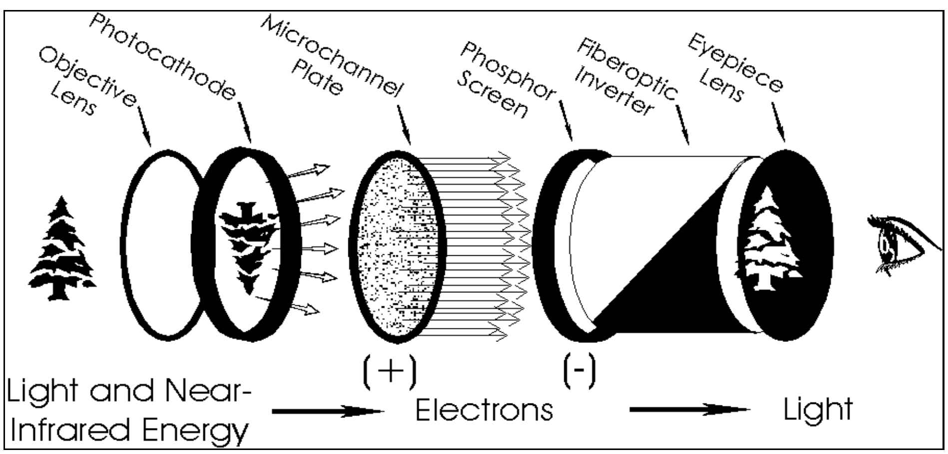
3.4. Night Vision Goggle Characteristics.

3.4.1. Introduction. The NVG is an advanced night vision system. The goggles chosen by the Air Force are binocular-style, helmet mounted, image intensification devices that amplify visible and near-IR energy. This amplification is a passive process, meaning no emissions are created by the goggles themselves.

3.4.2. Basic Components of the Image Intensifier Tubes (Figure 3.3). The NVG is a binocular assembly consisting of two image intensifier tubes which amplify available ambient light, otherwise called the image intensification (I2) process. The tubes are lightweight, fully adjustable, and are comprised of the following components.

- **Objective Lens.** The objective lens consists of a combination of optical elements which focus the incoming photons of light onto a photocathode. During this process the image is inverted.
- **Minus Blue Filter.** Coated onto the inside of the objective lens, the minus blue filter prevents certain wavelengths from entering the intensification process. This allows the use of properly filtered cockpit lighting to aid the pilot in viewing the cockpit instruments with unaided vision underneath the goggles. There are three standard classes of minus blue filters on goggles produced in the United States. The more common Class A filters use a 625 nm minus blue filter that blocks energy with a wavelength shorter than 625 nm--primarily wavelengths in the blue, green and yellow regions. Class B filters use a 665 nm minus blue filter to block energy with a wavelength shorter than 665 nm. This type filter reduces the NVG response in the red region and allows the use of more colors in cockpit lighting. Class C filters use a notch cutout in the minus blue filter that allows a specific wavelength of energy to pass throught the NVG and be seen by the aircrew. This is intended for viewing of cockpit instruments--specifically the HUD--throught the goggles.
- **Photocathode.** The photocathode has a layered coating of gallium arsenide, so that when photons impact it, it releases electrons to start the intensification process.
- **Microchannel Plate.** The microchannel plate is a thin wafer containing over a million glass tubules that channel the electrons exiting the photocathode. The tube walls are coated with a lead compound so when an electron impacts the wall, it forces the release of more electrons. The tubules are tilted to ensure electron impact with the tubule wall. The result is a “cascade effect,” which is an essential part of the intensification process. As a result of this process, for every single electron that enters one of the tubules, over one thousand exit.
- **Phosphor Screen.** Applied to the output fiber optic system is a layer of phosphor that emits energy in the visible spectrum (light) when struck by electrons. Thus, as the electrons strike the phosphor, an image is created. Due to the type of phosphor selected for NVGs, the resultant image is green.
- **Fiberoptic Inverter.** The fiber optic inverter reorients the image that was inverted by the objective lens.
- **Diopter (eyepiece) Lens.** The diopter lens is the final optical component of the image intensifier tube. The lens is adjustable and focuses the image onto the retina.

Figure 3.3. NVG Components and the Image Intensification Process (para 3.4.2).



3.4.3. Direct view and indirect view NVGs (Figure 3.4). Binocular style NVGs are classified into two major types: Type I NVGs, or direct view, and Type II, or indirect view.

- **Type I.** Type I NVGs present an image directly from independent image intensifier tubes to each eye. The AN/AVS-6 Aviator’s Night Vision Imaging System (ANVIS) is an example of this type goggle. In general, the optical performance of direct view NVGs is better than indirect view systems and is the type currently used by the Air Force.
- **Type II.** In a Type II NVG, the image intensifier tubes are not located directly in the line of sight, but are located above the eye position. The image from each intensifier tube is focused and reflected onto combiner positioned in front of each eye. The combiner is designed to reflect some energy (the NVG image) and to allow some energy to pass through, thus allowing the pilot to “look through” to see other items of interest (e.g., HUD information). Due to the

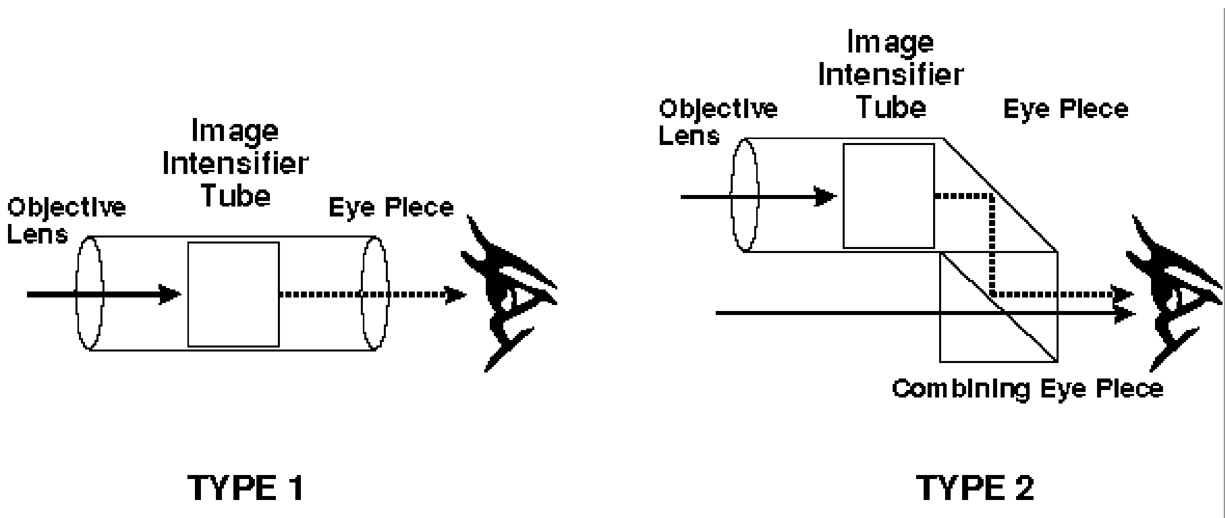
design of the system, there is less obstruction to the pilots field of view when looking around/under the goggle. CATS EYES is an example of this type NVG and is primarily used in Navy and Marine Corps fighter/attack aircraft.

3.4.4. NVG Characteristics.

3.4.4.1. Gain. Gain refers to the ratio of output to input, or the amount of energy the intensification process produces relative to the amount that entered the intensification process. A NVG has circuitry that determines the amount of energy entering the intensification process, and this circuitry automatically controls the level of intensification needed to produce images of consistent brightness over a wide range of illumination levels. The control of the level of intensification is called automatic brightness control (ABC). At some point, the ability of the intensifier to increase gain is reached and image brightness and quality begin to degrade. Image degradation caused by lowering light levels can be very insidious and leads to problems for the aircrew.

3.4.4.2. Image color. The NVG image appears in shades of green. Since there is only one color, the image is said to be monochromatic.

Figure 3.4. Type 1 and Type 2 NVGs (para 3.4.3).



3.4.4.3. Visual performance. When compared to the human eye under daylight conditions, your vision is limited while utilizing NVGs--detection ranges increase and recognition of objects, terrain and targets can be severely limited. While NVGs can be vastly superior to the human eyes' performance under night conditions, **NVGs DO NOT TURN NIGHT INTO DAY.**

3.4.5. NVG Limitations.

3.4.5.1. Visual limitations. The following visual limitations are common to NVGs.

3.4.5.1.1. Field of view. Field of view (FOV) refers to the total instantaneous area covered by the NVG image. Current Type I NVGs (AN/AVS-6 or F4949) have 40 degree FOV, while CATS EYES, a Type II system, has approximately 30 degrees FOV. Regardless of the FOV of any particular system, it is considerably less than the eye's normal FOV of 120 degrees by 80 degrees. This loss of peripheral vision can contribute to the onset of illusions.

3.4.5.1.2. Resolution. Resolution refers to the capability of the goggle to present an image that makes clear and distinguishable the separate components of a scene or object. Though not technically accurate, it is easiest to discuss resolution in terms of Snellen visual acuity (the same system used for vision testing during flight physicals). Current NVGs have a resolution capability of 20/25 to 20/40 Snellen. Though quite an improvement for NVGs, the performance is still less than 20/20, which is accepted as "normal day vision." However, NVG performance far exceeds the eye's unaided visual performance at night, which is approximately 20/200 to 20/400. It should be noted that while NVGs have a rated acuity of 20/25 to 20/40 Snellen, this is the best an aircrew can expect to achieve under optimum conditions. There are many factors that affect NVG operations and degrade the expected acuity. These factors are discussed in the next section.

- NVGs will not correct for sight deficiencies such as myopia or astigmatism. If you wear glasses during the day, you will still have to wear them when flying with NVGs to see properly.

3.4.5.1.3. Depth Perception and Distance Estimation. Depth perception is the ability to determine where objects are located relative to each other, whereas distance estimation is the ability to determine the distance to something, such as the ground or a target. Depth and distance are discussed together because they use the same visual cues--binocular and monocular.

3.4.5.1.3.1. Binocular Cues. Binocular cues are needed for tasks relatively close (within an arm's reach) and for tasks at distances up to approximately 200 meters. Binocular cues, by definition, require the use of both eyes functioning together and include stereopsis, vergence and accommodation. When using NVGs to assess information at these distances, aircrews' binocular capability is seriously degraded due to the design of the goggle.

3.4.5.1.3.2. Monocular Cues. Monocular cues do not require the coordination of both eyes, and are available at and well beyond the distances at which binocular cues are available. Consequently, monocular cues appear to be most important for deriving distance information while flying. NVGs adversely affect monocular cues several ways. The decreased resolution of the NVG image results in a loss of sharp contrast and definition, both helpful for determining depth and distance. The limited FOV of the image diminishes depth and distance tasking by reducing the availability of cues. Also, anything adversely affecting the image (e.g., low illumination) will aggravate the problem. Examples of monocular cues used when flying include:

- **Size constancy.** If two hangers are known to be equal in size, the one appearing smaller must be further away.
- **Motion parallax (optical flow).** Nearer objects appear to be moving past more quickly than distant objects.
- **Linear perspective.** The convergence of parallel lines at a distance.

3.4.5.1.3.3. Avoiding Depth and Distance Problems. Be aware that anything adversely affecting the NVG image will also adversely affect the assessment of depth and distance. Avoid the tendency to fly lower or closer in order to see more detail. Over a period of time, aircrew "learn" how to assess depth and distance when flying in the same area. However, the "learned" techniques may not transfer to a new area where terrain and objects might be completely different in size and perspective. In general, there is a tendency for aircrew to overestimate how well they can see when using NVGs.

3.4.5.1.4. Contrast. As with resolution, contrast in the NVG image is degraded relative to that perceived by the unaided eye during daytime. Also, any bright light source within or near the NVGs FOV will further reduce contrast by reducing gain, creating veiling glare across the image, or both. Additionally, there are differences in sensitivity to contrast among crewmembers, which may lead to differences in image interpretation.

3.4.5.1.5. Dynamic Visual Cues. Dynamic visual cues provide information that helps to determine direction, altitude and speed. The three primary dynamic cues are:

- **Static Cue Motion.** Static cue motion is the summed effect of the change in one or more of the static cues caused by aircraft movement. Static cues include elevation, known size, and perspective. Central vision tracking is a method for seeing static cue motion and will be degraded when using NVGs.
- **Optical Flow.** Optical flow is the angular rate and direction of movement of objects as a result of aircraft velocity measured relative to the aviator's eyepoint. This provides our visual system the information necessary to interpret speed and direction of motion. If there is no relative motion, there is no optical flow. We use central vision to obtain optical flow information. Since visual acuity is degraded with NVGs, the optical flow cues will be degraded when compared to daytime cues.
- **Peripheral Vision Motion.** Peripheral vision motion is a subconscious method of detecting optical flow. It is dependent on a wide FOV and is the primary attitude sensory input. With the reduction in FOV due to NVGs, this cue is severely degraded and central vision tracking becomes the primary attitude detection means. This leads to one of the most insidious dangers when flying low altitude**--**flying at a lower than expected/allowed altitude. Just as in the day, visual acuity will improve as the aircraft gets closer to the ground. However, because of the reduction in peripheral vision motion, the ensuing "speed rush" that would indicate close proximity to the ground is degraded and controlled flight into terrain becomes a real danger.

3.4.5.2. NVG Scan. The reduction in FOV necessitates an active, aggressive scan on the part of the NVG wearer. By continually scanning, aircrew members increase their field of regard by increasing the mental image of the surrounding terrain, aircraft, and cultural features. This information can then be compared and added to the aircraft flight instruments. Aircrew members should establish a scan pattern that allows information from outside the cockpit to be merged with cockpit flight instrumentation. Fixating in one direction may be necessary for a short duration (e.g., identifying a waypoint), but the scan should be continued after just a few seconds. A crewmember's scan pattern may be disrupted during high cockpit workloads or when fatigued. Under these conditions, an extra emphasis needs to be given to the scan pattern, especially keeping the horizon in the field of regard.

3.4.6. Preflight Adjustment and Assessment.

3.4.6.1. Introduction. Following proper NVG adjustment procedures prior to each flight is imperative to ensure a safe and effective operational capability. Even a small error in goggle adjustment can significantly degrade NVG aided visual acuity. The problem is compounded by the fact that it is nearly impossible to measure a loss in visual acuity without a controlled test environment, which means you can lose visual performance and not realize it.

3.4.6.2. Tube alignment. The human visual system is designed to subconsciously fuse the images from each eye into a single image without the perception of two separate images. This concept is called binocular fusion. To ensure proper tube alignment, the aircrew member should be able to see a complete circle through each tube independently, and when viewed by both eyes the image should come close to forming a circle. Eye strain, fatigue, disorientation, or nausea can occur if NVG tube alignment errors are significant. If fusion becomes difficult, double images can form. Even if improperly aligned NVGs appear to have no adverse effects when used for short periods, they may prove intolerable when used for longer periods.

3.4.6.3. Assessment of Visual Acuity. The visual acuity obtained with both image intensifier tubes should always be at least as good as the vision of the best image intensifier tube alone. If this is not the case, the goggles should be returned.

3.4.6.4. Assessment of Image (Figure 3.5). The following image defects are typical deficiencies that can be either normal or defective in nature. It is important to understand the difference to determine the proper course of action.

3.4.6.4.1. Shading. Shading is a condition encountered when a full image can not be obtained and a dark area appears along the edge of the image. Attempt to eliminate shading by readjusting either the tilt or the interpupillary distance (IPD), or by shifting the helmet's position. Shading can also occur as a result of a shift in the microchannel plate caused by the goggles being dropped or handled roughly. If shading can not be corrected by readjustments or by repositioning the mounting bracket on the helmet, turn the goggles in for maintenance.

3.4.6.4.2. Edge glow. Edge glow appears as a bright area along the outer edge of the image. It can result from an incompatible light source outside the goggle FOV, a shift in the microchannel plate due to mishandling, or a power supply problem within the tube assembly. If edge glow is noted, move your head or cup your hand around the periphery of the objective lens in an attempt to alleviate the condition. If the edge glow does not disappear, turn the goggles in for maintenance.

3.4.6.4.3. Honeycomb. At times of very high luminance, a hexagonal (honeycomb) pattern may be visible across the intensified field of view. This pattern is a result of the manufacturing process during which the fiber optic inverter is assembled within the tube. Normally it is faint in appearance and does not affect NVG performance. Should it appear as a bold outline or during low luminance conditions, turn the goggles in for maintenance.

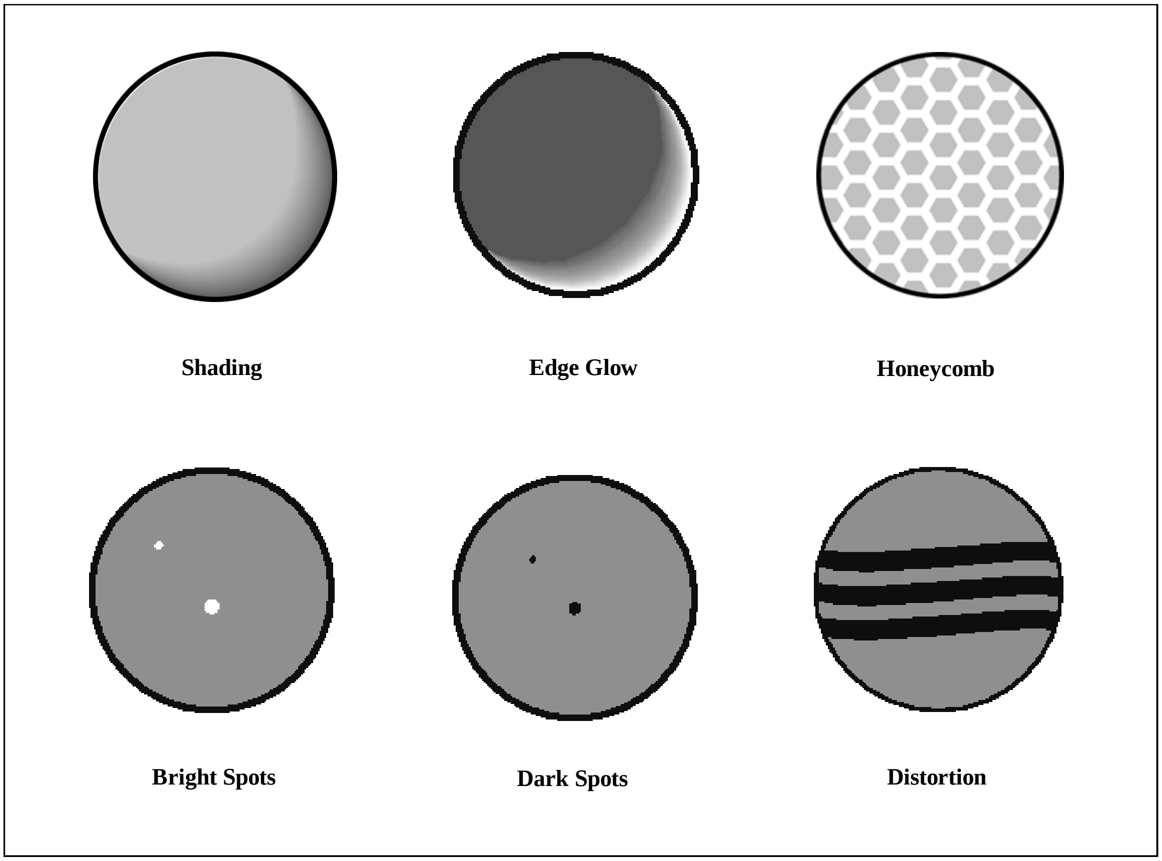
3.4.6.4.4. Bright spots. Bright spots are the result of irregular emission points on the photocathode, usually occurring during the manufacturing process. Because these spots are normally detected during the quality control process at the manufacturer, you will seldom see them. However, if an NVG has an excessive number of spots present in the image, or if the spots are distracting, turn the goggles in for maintenance.

3.4.6.4.5. Dark spots. Dark spots are simply the bright spots described above that have been corrected at the manufacturing facility. This correction is accomplished by exposing the light spots to laser energy and burning out that portion of the photocathode. Dark spots may also be caused by material allowed to enter the system during maintenance. NVG acquisition contracts usually include a specification that limits the number, size, and location of dark spots. Nevertheless, if you are distracted by the dark spots, even if the NVG is within specification, turn the goggles in for maintenance.

3.4.6.4.6. Distortion. The two most common types of distortion are bending and shear. Bending distortion results in the image having a wavy appearance, usually in a horizontal or vertical direction. Shear distortion results in a choppy appearance somewhere in the image. If distortion is present and likely to interfere with normal operations, do not use the NVGs. Flying with tube distortion can cause problems in distance and altitude estimations.

3.4.6.4.7. Scintillation. A sparkling effect normally occurs in the NVG image during low illumination conditions as a result of increased goggle gain and system noise. In flight, it can be an indication of decreasing illumination caused by such things as deteriorating weather conditions or flight into shadows.

Figure 3.5. NVG Image Defects (para 3.4.6.4).



3.5. Factors Affecting NVG Operations.

3.5.1. Cockpit Lighting.

3.5.1.1. Basics. NVG compatible cockpit lighting allows the crewmember to see cockpit instruments underneath the NVG while not measurably affecting NVG performance. Although NVG filters allow the use of cockpit lighting that will not adversely effect gain and image quality, unfiltered aircraft lighting is incompatible. If the lighting is not properly modified, it will emit wavelengths that affect NVG performance. There are aircraft in the inventory that have not been fully modified to be NVG compatible. The following points are provided for clarification:

- Just because a light is green or blue does not mean it is compatible. When the filament in a light glows, it releases a significant amount of near-IR energy which will affect NVG gain and performance. Light bulbs and other energy sources in the cockpit must be modified in some manner to block the emission of all energy to which NVGs are sensitive in order to make them NVG compatible.
- Turning down the brightness of incompatible cockpit lighting will not make them compatible because NVGs are also sensitive to the near-IR energy emitted by the lights. Attempting to turn down lighting to reduce the effect on goggles can be a two edged sword--the NVG image will still be degraded and vital instruments may not be readable with the unaided eye.
- An incompatible light does not have to be within the NVG FOV for it to have an effect on gain.

3.5.1.2. Procedures. MAJCOMs have specific lighting modification procedures if your aircraft cockpit lighting is not NVG compatible. When modifying your cockpit, remember that the Air Force requires you to always have primary flight instrumentation present and properly illuminated. It must provide full-time attitude, altitude, and airspeed information; an immediately discernible attitude recognition capability; an unusual attitude recovery capability; and complete fault indications.

3.5.2. Transparency Transmissivity. Another impact on NVG performance is the degradation caused by windscreens, canopies, or other transparencies through which aircrew must look. Some transparencies transmit visible wavelengths fairly well, but near-IR wavelengths very poorly. Since NVGs are sensitive to near-IR wavelengths, transparencies that “trap” much of that energy will degrade NVG performance. All transparencies absorb near-IR energy to some extent, so there will be some goggle degradation in your cockpit.

3.5.3. Weather and Visibility Factors. Any atmospheric condition which absorbs, scatters, or refracts illumination, either before or after it strikes the terrain, will effectively reduce the usable energy available to the NVG. This reduction, in turn, degrades our ability to see key features critical for flight. The exact amount of reduction is difficult to predict because a common factor cannot be applied to each condition.

3.5.3.1. Clouds. Because of their variability, it is very difficult to predict the effect clouds may have on NVG operations. In general, NVGs easily "see" clouds that are dense but may not see clouds that are less dense. In the case of the more dense clouds, both visible and near-IR energy is reflected and the NVG can see the cloud (just as you can see the cloud unaided if there is enough light), especially if silhouetted against the night sky. However, dense clouds will reduce the amount of illumination striking the ground and therefore reduce the luminance available for NVG use. Thin (less dense) clouds have more space between their particles. Because the near-IR wavelength is slightly longer, it has a greater chance of passing through these type clouds than does the shorter visible wavelength. It is possible for the thin and wispy clouds (which may be seen with the naked eye during daytime) to be invisible when viewed through the NVG. This potential invisibility is possible given three conditions:

- The clouds are less dense,
- The clouds are low level, and set in against the terrain rather than being silhouetted against the night sky, and
- Ambient illumination is either very high or very low.
- The invisibility of thin clouds can create a severe hazard for NVG operations. Even though a cloud is "invisible," you may not be able to see the terrain behind it because the cloud reduces luminance, which in turn reduces scene contrast and texture. In turn this may produce a false perception of distance, resulting in the pilot either not seeing the terrain or thinking it is farther away than it actually is. Additionally, the cloud may get progressively thicker, allowing the pilot to progress into the cloud without initially perceiving it or the terrain beyond. If a cloud is detected, the perception may be that it is at a distance.

3.5.3.2. Fog. Fog is another atmospheric condition of concern for the NVG operator. Its effects on goggles are similar to those of clouds, but there is a greater tendency for fog to be less dense and therefore more of a problem. It is important to know when and where fog may form in your flying area. Typically, coastal and mountainous areas are most susceptible.

3.5.3.3. Rain. Like clouds, the effect rain may have on goggle performance is difficult to predict. Droplet size and density are key ingredients to its visibility or invisibility. Light rain or mist may not be seen with NVGs, but will affect contrast, distance estimation, and depth perception. Heavy rain is more easily perceived due to the large droplet size and energy attenuation.

3.5.3.4. Snow. Snow occurs in a wide range of particle sizes, shapes, and densities. Snow crystals, while small in size, are generally large in comparison to the wavelength of visible light and near-IR energy, and will easily block or scatter those wavelengths. As with clouds, rain, and fog, the more dense the airborne snow, the greater the effect on NVG performance. On the ground, snow has a mixed effect depending on terrain type and the illumination level. In mountainous terrain, snow may add contrast, especially if trees and rocks protrude through the snow. In flatter terrain, snow may cover high contrast areas, reducing them to areas of low contrast. On low illumination nights, snow may reflect the available energy better than the terrain it covers and thus increase the level of illumination.

3.5.3.5. Sand, Dust, Smoke and Similar Obscurants. The effect of sand, dust, smoke and similar obscurants is similar to that created by the weather factors. However, the individual particulates in these obscurants are usually far more dense, which means they can block energy even if less concentrated.

3.5.3.6. General. All the atmospheric conditions described above reduce illumination levels. Recognition of this reduction in the cockpit is very difficult. The change is often a very subtle reduction in contrast which is not easily perceived with NVGs. Cues can be very subtle and the crewmember will have to stay aware to catch their significance. Common cues to reductions in ambient illumination due to visibility restrictions include loss of celestial lights, loss of ground lights, reduced contrast, reduced depth perception or distance cues, reduced acuity or resolution, increased graininess or scintillation, and a more pronounced "halo" effect around incompatible light sources outside the aircraft.

- Cockpit lighting, weather, transparency effects, the illumination level, and terrain type all have an effect on NVG performance. The visual acuity you achieve in the eye lane will usually not be what you get in the aircraft during the mission--it will usually be less. It is therefore imperative you maximize NVG performance before flight and avoid doing anything to the goggle during flight to disrupt it (e.g., readjust the diopter). Maximizing the NVGs performance will help offset the negative effects discussed.

3.5.4. Circadian Rhythm. Circadian rhythm is the body's internal clock. It is an innate cycle that varies from person to person and has a duration of approximately 25 hours for most people. It is affected by a multitude of physiological functions and environmental variables, and partly determines each person's performance level. You will never be as good at your job at night as you are in the day because your performance degrades when your physiological functions are at their ebb. Performance is generally degraded during the hours of darkness, but a person's lowest performance usually occurs between 0300 and 0600, called the circadian trough.

3.5.4.1. Prevention. Reduced performance exists during nighttime regardless of your proficiency, motivation or rest. The following guidelines can help lessen these effects, and may result in improved performance during the time when NVGs will be used.

- **Proper rest.** The overall effects of circadian rhythm cannot be changed, but it can be manipulated. A well rested person will likely have a higher level of performance during their circadian trough than when sleep deprived. Additionally, the low portion of the trough can be shifted based upon sleep habit patterns. For example, if you compare the trough of a morning person (goes to bed early and gets up early) to a evening person (stays up late and gets up late), you will see the troughs are shifted in direction but not in depth. In other words, each group will demonstrate the same degree of low performance, but at slightly different times.
- **Proficiency and Motivation.** Proficiency and motivation can have significant effects on the level of performance. A highly proficient (trained) person will perform better at night, but will still not perform as well as during the daytime. The circadian trough may be raised, but not eliminated. Motivation has a profound effect on performance, and may elevate the level close to that achieved during daytime, but only for very brief periods.
- **General.** Even though the circadian cycle cannot be reversed, or the circadian trough eliminated, crewmembers can enhance their nighttime performance by getting proper rest, maintaining a high level of proficiency and staying motivated.

3.5.5. Fatigue. Fatigue is a common problem that has an adverse effect on performance during any operation, but very commonly at night. It cannot be avoided, but it can be controlled given a reasonable set of guidelines. In order to implement these guidelines, it is important to know the types of fatigue so you can recognize and manage them.

3.5.5.1. Types. The following are three types of fatigue.

- **Acute fatigue.** Acute fatigue is the tiredness or exhaustion experienced after any demanding mental or physical activity. It is short-term, characterized by a feeling of being worn out, and will usually be relieved by rest.
- **Cumulative fatigue.** Cumulative fatigue is less intense than acute fatigue and occurs over time as a result of inadequate rest and/or after a continuous heavy workload. It is associated with a feeling of being "burned out." It usually takes the body longer than one night's rest to recover normal energy levels.
- **Circadian fatigue.** Circadian fatigue is the tiredness produced either by shifting the sleep/wake cycle, or experiencing transmeridian travel (jet lag).

3.5.5.2. Effects of Fatigue. Fatigue poses a serious threat to night mission accomplishment. In many ways fatigue is very similar to hypoxia; performance is subtly eroded, recognition is difficult, and there is an unwillingness to do anything about it. Fatigue has the potential to contribute to the most common causes of human factors-related accidents. Those causes and how fatigue effects them include:

- **Loss of Situational Awareness.** Computational and abstraction skills become degraded. In other words, the ability to restructure the various parts of the night scene are slowed, impacting the time required to interpret instruments and displays.
- **Channelized Attention.** Attention span and vigilance are reduced, important elements in a task series are overlooked, and scanning patterns essential for situational awareness break down--usually due to fixation on a single instrument or object. Fatigue usually results in errors caused by omission of a task as opposed to performing a task incorrectly.
- **Complacency.** Complacency allows for acceptance of situations that would not normally be permitted. Critical but routine tasks are often skipped because fatigue reduces overall willingness to respond.
- **Unrecognized Spatial Disorientation.** The most difficult tasks for fatigued aviators are those that require complex and swift decisions, or planning. This is because short-term memory is seriously affected by fatigue. The impact could be so great that the crewmember may not recognize a bad situation or attempt corrective action.

3.5.5.3. Coping with Fatigue. Night missions can combine all three types of fatigue. When combined, the effects are synergistic and not simply additive. Combining normal squadron duties with the workload of night missions creates acute fatigue on continuing basis. Shifting to a night flying schedule will cause circadian disruption, and when you add the effect of cumulative fatigue, it becomes clear that aircrew members must work to stay alert in a potentially hostile environment. There are ways to reduce the impact of fatigue, thus improving performance and increasing safety. The easiest way to overcome or delay the effects of fatigue is through task familiarity and motivation. Fatigue, however, will eventually take its toll as performance will drop even under these conditions of additional effort. Understanding that there is a natural low in daily performance and making an extra effort appears to be the best way to compensate for this problem. Extra effort in this case means being alert to the causes and efforts of fatigue, and not pushing your performance envelope after an already long day. It is also important for crewmembers to look for signs of fatigue in each other.

3.6. Night Operations. Even though we use a lot of modifying words like "normally" and "usually" in the next section, there are no constant rules about interpreting the NVG environment. If it were possible to identify conditions that always give a concrete answer, those conditions would be presented here. Instead, the NVG environment is always changing, so you must always be aware of what cues are presented and work to interpret them. Even then, beware of the potential misperceptions or illusions in any NVG scene.

3.6.1. Terrain Interpretation. Three major characteristics influence our ability to see terrain features or objects and distinguish differences. Due to the variability of the weather, the illumination level, and the moon angle, any given scene may look radically different on consecutive nights. A basic understanding of NVG operations requires the crewmember to blend the following considerations with an awareness of those changing conditions over different types of terrain.

3.6.1.1. Terrain Albedo (Reflectivity). Differences in terrain albedo, or reflectivity, will greatly influence luminance. For example, surfaces such as snow will reflect more energy than surfaces like asphalt or dark rock. Since NVGs intensify reflected energy, different albedos become critical in interpreting the NVG scene. Albedo will also vary with specific conditions of terrain even though the terrain type remains constant. For instance, dry sand is twice as reflective as wet sand.

3.6.1.2. Terrain Contrast. Terrain contrast is a measure of the difference between the reflectivity of two or more surfaces. The greater the differences in contrast, the more "normal" the scene appears in the NVG image, and the easier it becomes to pick out objects. Contrast generally improves with higher light levels, but there comes a point where there is actually too much light. This is usually noted when flying over low contrast terrain during high illumination conditions. Normally, however, as the ambient light level increases, overall definition is improved. Some examples of the effects of contrast in varying conditions are below.

3.6.1.2.1. Roads. The ability to detect roads with goggles depends primarily on the albedo difference between the road and the surrounding terrain. For example, the highly reflective surface of a concrete highway is easily identified in a grassy area during most illumination levels because of the difference in their albedos. However, asphalt roads are usually difficult to identify in heavily vegetated areas because both the asphalt road and the vegetation absorb available energy, and therefore have similar albedos. Conversely, in desert areas the reflective sand can make asphalt roads easily detectable.

3.6.1.2.2. Water. Still water, when seen with NVGs, normally looks dark when viewed at high angles from higher altitudes. Under low illumination, there is very little contrast between a vegetated landmass and a body of water. In desert areas, lakes and small bodies of water are normally detectable as a dark area in a light background. Lakes in a forested area are more difficult to detect due to the low reflectivity of the surrounding terrain. As light levels increase, land-water contrast increases. Due to the reflective nature of water, when over-flying large bodies of calm water, the stars appear to move across the surface as the angle of reflection is changed by the movement of the aircraft. This phenomenon may contribute to or induce the onset of spatial disorientation. Any action on the water caused by wind, such as white caps, may improve the contrast, aiding in surface identification. Over the ocean, the normal wave action breaks up reflections, thus reducing the problem. As in non-NVG flight, however, all night flight over open water is best performed with a heavier reliance on primary instruments.

3.6.1.2.3. Open fields. Contrast is usually very good over fields that are tended for crops. Various types of vegetation differ widely in their near-IR reflectance characteristics. For example, due to differences in the near-IR reflectance of chlorophyll, an oak tree will appear brighter than a pine tree. The same holds for crops. However, if flying over a large area of similar vegetation, contrast will be reduced. Additionally, the differences in the surface texture due to plowing are very apparent. A freshly plowed field may lack vegetation, but may produce a good NVG image when the coarse texture of the upturned soil contrasts well with the relatively undisturbed soil between the rows.

3.6.1.2.4. Desert. Open desert without vegetation can produce a washed-out NVG image. This is due to the high reflectivity of the sand and poor contrast offered by the lack of different albedos in the scene. Desert environments which have bushes, low trees, and cacti provide better contrast cues, allowing for more detail in the image. In general, flying over this type of terrain is similar to flying over water and is best accomplished with more reliance on your instruments.

3.6.1.2.5. Mountain Ranges. Normally, mountain ranges can easily be identified if the lower reflectivity of the mountains contrast with a lighter, more reflective desert floor. However, if ridges between your aircraft and a distant ridge have similar albedos, the intermediate ridges can for all practical purposes be "invisible." Low, rolling terrain with the same reflectivity as the surrounding terrain can also blend together and be difficult to distinguish. These effects are more pronounced in low-light situations, but can occur under any conditions.

3.6.1.2.6. Forested areas. Heavily forested areas do not reflect energy efficiently, and solid canopied forests or jungles look like a dark mass at night. Excellent contrast does exist between deciduous (leafy) and coniferous (pines, firs, etc.) trees as well as between open fields, exposed rocks, and surrounding forest areas.

3.6.1.2.7. Snow. Fresh, wet snow reflects approximately 85 percent of the energy reaching it, thus providing the best natural reflectivity of any terrain surface. Under high illumination, this can provide excessive light which can, in turn, lower intensifier tube output and decrease resolution. During periods of predicted low illumination conditions, snow may add to the illumination level. Snow on the ground can also be a factor for flight planning; landmark recognition may be difficult if deep snow obscures prominent terrain features.

3.6.1.3. Terrain Shadows. Shadows form at night just as they do during the day, and anything blocking moonlight will create a shadow. The amount of terrain obscuration within a shaded area is dependent on the amount of ambient illumination and relative position of the moon. The smaller the moon disc, the darker the shadowed area and the more difficult to see detail. However, never plan on seeing any terrain features within shadows, regardless of the moon disc size.

3.6.2. NVG Misperceptions and Illusions. While most misperceptions and illusions encountered during NVG operations are simply a carryover of those experienced during daytime flight, others are specific to the NVGs themselves. Reduced resolution, limited field of view, and susceptibility to obscurants can intensify misperceptions and illusions. The most common NVG misperceptions and illusions are discussed below.

3.6.2.1. Depth Perception and Distance Estimation Errors. A common belief is that depth perception (DP) and distance estimation (DE) capabilities do not exist when using NVGs. It is true that these abilities are degraded by environmental conditions and goggle limitations, but techniques can be developed to assess depth and distance. The most helpful depth and distance cues are those with which the aircrew is most familiar. Flying over familiar terrain and culture features can reduce DP and DE errors. When flying over different terrain with unfamiliar features, serious errors in DP and DE can develop. For example, if someone normally flies over terrain with 30 foot trees, but is then deployed to an area populated with 5 foot shrubs, that person may fly lower than normal trying to make the scene look as it normally does. Using visual information alone, that person would likely think they were higher than they actually were. In this situation, bringing a radar altimeter into the cross-check would help minimize the effects of the illusion. Overall, the best way to train for the lack of DP and DE cueing is through proper planning, training, and a good discussion of differences between the deployed location and the normal area of operations. Training over a wide variety of terrain, features, and illumination levels can build the experience level of the aircrew to handle varying situations. Additionally, a thorough pre-brief should be incorporated to familiarize aircrew with the cues expected in the area of NVG operations. When viewing light sources with NVGs, a technique that may help DP and DE is to look at the source with unaided vision. By looking underneath or around the goggles, not only can colors be determined, but the halo effect produced by the NVGs is eliminated. This additional information can be combined with the information presented in the NVG scene to improve the accuracy of your assessments.

3.6.2.2. Terrain Contour Misperceptions. Terrain contour misperceptions are exaggerated by anything that degrades the NVG image. The following are a few techniques to aid the aircrew in correct terrain perception.

- **Discriminating Between Near and Distant Terrain.** One way to discriminate between near and distant terrain that contain little contrast difference is being attentive to motion parallax between the two. For example, a hidden ridgeline close to you may be highlighted by noting its movement relative to a distant, higher mountain.
- **Gradual Changes in Terrain Elevation.** Gradually rising or descending terrain can be very difficult to assess when the terrain is low contrast. It becomes even more difficult when there are few cultural features available for comparison. To aid in detection of the gradual changes, an aggressive NVG scan must be maintained. By scanning aggressively, indicators of changes in terrain elevation may be picked up in areas other than directly in line with the flight path. Also, an aggressive instrument scan--when altitude, mission, and terrain type allow--can provide additional inputs to the developing situation.
- **Maintaining Scene Detail.** If for any reason scene detail is reduced, there may be a tendency to fly lower in an attempt to regain the lost detail. In the worst case, this can lead to ground impact. Examples of when scene detail can be reduced include transitioning from an area of high contrast to one of low contrast, or when transitioning from an area of high illumination to an area of low illumination.

3.6.2.3. Undetected or Illusory Motion. Motion illusions experienced by aircrews are usually due to flights over areas of reduced contrast, or a sudden loss of contrast and flow cues. This can result from the lack of perceived “flow” information in the NVG image and may create the illusion that the aircraft has slowed down or stopped. This situation can induce spatial disorientation, especially if coupled with other factors such as loss of the horizon. An increased instrument scan will help alleviate the problem. Another insidious aspect of undetected motion is when an aircrew perceives they are motionless. Helicopter crews hovering over low contrast terrain, whether a large field or over open water, can actually be moving at fairly high speeds without knowing it. Without cues to provide stimulus to the visual system, this movement can go undetected and is very dangerous. Again, this is a known problem even during daytime, but the decreased resolution and FOV of the NVG image can accentuate the effects.

3.6.2.4. Recommendations. Susceptibility to illusions and misperceptions can be lessened by maximizing visual acuity. The best way to accomplish this is proper preflight adjustment and assessment of the goggles, ensuring the best NVG image. In-flight attentiveness is another building block to ensure NVG effectiveness. As stated earlier, reliance solely on visual cues will nearly always result in a flight path that is lower, closer, or steeper than intended, so the aircraft instruments must be readable and included in your cross-check. Use all information available to you, not just one piece of the puzzle. By using the entire picture, you lessen the likelihood of relying too much on NVGs. As usual, an aggressive scan is required to maintain situational awareness and spatial orientation.

3.6.3. Emergency Situations. In general, consider the type of emergency and what actions might be required from the pilot or the crew. If the NVGs will not be useful during emergency procedures, consider removing them. However, if you can still gain valuable information from the NVGs, aircrews may continue to use them.

3.6.3.1. Ejection. Ejection seat aircrew members must remove the NVGs prior to ejection unless they are ejection seat compatible. During the ejection sequence, with the NVGs in place on the helmet, fatal neck injuries can occur due to the forward center of gravity and weight of the goggles. It is for this reason that aircrews not leave the NVGs in a raised position during emergencies that may lead to an ejection sequence. It is probable that you will forget you are wearing them in a highly stressful situation.

3.6.4. Inadvertent IMC. One of the most dangerous situations that can be experienced with NVGs is flight into undetected meteorological conditions. The inability of the NVGs to see various areas of moisture can lull the aircrew to continue further into IMC to a point where there is virtually no visual information. This can result in a gradual loss of scene detail and place the aircrew in an area of heavy moisture and, in the low-level environment, place the aircrew in a potential conflict with masked terrain. The following NVG cues will help alert you to impending IMC:

- Halos surrounding incompatible light sources outside the cockpit (e.g., external lights from another aircraft) may change in appearance. Normally sharp edges to the halos can become less distinct and the halo may appear larger due to energy dispersion from the moisture.
- A gradual loss of scene detail, visual acuity, or terrain contrast.
- Partial or complete obscuration of the moon and stars.
- An increase in scintillation.
- The glow or flash from your aircraft external lights/strobes/landing lights/searchlights may become visible or intensify.

Looking underneath or around the NVGs with the unaided eye can aid in detecting IMC, but be aware that you can be in precipitation without seeing it in the NVG image. Use all the cues available to you.

3.6.5. Spatial Disorientation. Spatial disorientation can occur at any time during flight. Although NVGs usually improve situational awareness and reduce the possibility of spatial disorientation, they can also enhance momentary disorientation. This is due to the limited field of view and lower resolution. Maintaining spatial orientation at night requires complex conscious processing of data from various instruments, displays, and references. The task of maintaining spatial orientation competes with the usual tasking of navigation, terrain masking, threat avoidance, etc. Add to this the fact that fatigue occurs more frequently at night and it is easy to understand why the incidence of spatial disorientation in this environment appears to be logarithmic as variables are added. Constant vigilance and a good scan pattern, both inside and outside the cockpit, must be maintained to help prevent spatial disorientation. Keeping the horizon in the NVG scan can help avoid spatial disorientation. If you feel disoriented, react in exactly the same way as if you were on a non-NVG flight.

3.6.5.1. Preventing Aircraft Mishaps Due to Spatial Disorientation. Refer to AFMAN 11-217, Vol 1, for a discussion on preventing aircraft mishaps due to spatial disorientation.

3.6.6. Overconfidence. Aircrew members must not become over confident in the capabilities of NVGs. Goggles are only one tool used during night flight, and many situations can degrade or eliminate their effectiveness. Aircrews need to be cognizant of NVG limitations and prepared to transition to other flight aids, primarily aircraft instrumentation. Remember that NVGs do not turn night into day. After your initial NVG flying experience, there may be a natural tendency to be overly confident in your abilities. While, over time, there will undoubtedly be an increase in your skill level, it is not enough to compensate for the multiple variables in the night environment. The complacent mind-set could be a setup for a mishap.

3.7. Other Night Vision Device Systems.

3.7.1. Introduction. Forward looking infrared (FLIR) systems will be briefly introduced to help you gain an appreciation for their difference from NVGs, as well as to demonstrate how FLIR and NVGs compliment each other.

3.7.2. FLIR Systems. FLIR technology is based on the fact that all objects warmer than absolute zero emit heat. FLIR can discriminate between objects with a temperature of less than one degree difference, or of the same temperature if they emit heat at different rates. The rate of emission depends upon composition of individual objects. FLIR sensors detect the differences in the thermal properties of these materials and creates an image on either a head up or head down display. This process, called thermal imaging, results in monochromatic image for the aircrew that can be gray or green depending on the display.

3.7.3. Comparison of FLIR and NVG (Table 3.1). NVGs and FLIR systems are complimentary sensors and can aid mission accomplishment through their integration.

Table 3.1. NVG and FLIR Comparisons.

NVG	FLIR
use reflected energy (visible light and near IR)	use emitted energy (mid or far IR)
images reflective contrast	images thermal contrast
requires at least some illumination	totally independent of light
penetrates moisture more effectively	penetrates smoke and haze
attenuated by smoke, haze and dust	attenuated by moisture (humidity)

Chapter 4

GROUND-BASED NAVAIDS

4.1. Automatic Direction Finding (ADF) Equipment.

4.1.1. Nondirectional Radio Beacon (NDB).

4.1.1.1. The NDB is still an important NAVAID around the world. In many countries overseas the low altitude airways system (brown system) is based on the NDB. Here in the US there are numerous airports, (in the Midwest for example), where there is an NDB on the airfield, but no VOR or TACAN within 30 miles or more.

4.1.1.2. Many NDBs are weak with only limited range, and some NDB approaches don't allow you to descend much below VFR minimums. However, an NDB approach does offer a safe means of descent and a way to locate an airport in marginal VFR or IFR conditions.

4.1.1.3. In the US there are hundreds of uncontrolled airports served by NDB approaches that would otherwise be inaccessible on IFR days. For such fields, the NDB offers relatively inexpensive installation and low maintenance; more sophisticated facilities would be cost prohibitive. At larger airports, the Locator Outer Marker (LOM) is a small NDB that gives position information during an ILS approach.

4.1.1.4. Although NDB approaches offer less course accuracy than other instrument approaches, the minimums are reasonably low, allowing arrivals in fairly bad weather conditions. Minimums for NDB approaches with no FAF can be as low as 350 feet. For NDB approaches with a FAF, the minimums can be 300 feet, depending on obstacles. Visibility requirements are about 1 mile.

4.1.1.5. The NDB is not used in the airway system in the 48 states, but low frequency beacons are still used in parts of Alaska, Canada, and many foreign countries to form an en route airway structure.

4.1.1.6. Lack of experience with ADF procedures and perhaps incomplete or confusing training makes many pilots reluctant to fly NDB approaches. Since the NDB system simply points to the chosen station, it is easy for pilots to misinterpret their position; therefore, it is important pilots understand and frequently practice NDB approaches. However, these approaches are a valuable option to use when your aircraft is capable of flying an NDB approach and other navigation equipment is unavailable or inoperative. The NDB is not the most accurate method of finding an airport because it requires considerable skill and technique on the part of the pilot, but it is much better than trying to get to an airport in bad weather without using an approach procedure.

4.1.2. ADF Equipment.

4.1.2.1. Simply put, the ADF equipment is in the airplane, and the NDB equipment is on the ground. The ADF is a low frequency radio receiver. The AN/ARN-7 will receive any frequency between 100 and 1,750 kilohertz (kHz). Most other low frequency radio receivers have a frequency range of 190 to 1750 kHz. The IFR En Route Supplement lists the location and frequencies of the NDB and low frequency radio ranges. The 540 to 1650 kHz range contains the commercial AM (Amplitude Modulation) broadcast stations, and the 190 to 535 kHz frequency range is assigned to the NDBs. Whenever possible, use an NDB. Commercial broadcasting stations use a highly directional radiation pattern are not flight checked for navigational use. Nor does the station identify itself often enough to be used legally for IFR flight. Positive identification of the commercial station is imperative. Another consideration to take into account is where exactly the transmitter is located, which may be far from the station.

4.1.2.2. The NDB transmits a signal (AM) with an audible Morse code identifier. Some NDBs may also carry voice transmissions (weather, etc.) which override the identifying code. When using an NDB for navigation, it is important to tune and identify the station carefully.

4.1.2.3. Low frequency signals are not limited to Line Of Sight (LOS) reception like the VHF signals are. For this reason, if the transmitting power is high enough, the NDB signal may be usable at low altitudes and at long distances from the station.

4.1.2.4. There are presently several different models of ADFs in use in the Air Force. Specific instructions for the type of ADF in your aircraft are contained in the aircraft Technical Order (TO). The new digital versions are easy to operate. Tuning is done by simply dialing the required frequency and then confirming the aural Morse code identifiers. Selecting the "antenna" position disconnects the search (direction finding) system, which allows a more readable signal without bearing information being provided (usually slaves to wing tip index). The older versions are somewhat more complex.

4.1.2.5. A typical older type of ADF receiver may include all or some of the different modes of operation (components) described below:

4.1.2.5.1. COMP or ADF. Both the loop antenna and sensing antenna are in use. Automatic bearing information is shown by the bearing pointer, and the volume level is maintained automatically at a constant level as the aircraft flies toward or away from the station.

4.1.2.5.2. ANT. The receiver is connected to the sensing antenna for low frequency audio reception. No bearing information is provided.

4.1.2.5.3. LOOP. The receiver is connected to the loop antenna only. Bearing information is obtained by rotating the loop manually with the L/R switch.

4.1.2.5.4. LOOP left/right (L/R) switch. The loop switch operates when the function switch is in LOOP. When the loop is rotated with the L/R switch, a bearing (null) or a maximum audio signal can be obtained. The aural null will be found when the plane of the loop is perpendicular to a line drawn to the station. A null exists when the needle is pointing directly at or away from the station.

4.1.2.5.5. Continuous Wave (CW)/VOICE switch or Beat Frequency Oscillator (BFO). When the switch is in CW position, a 900 hertz (Hz) tone is superimposed on any signal being received. This provides a constant signal. At VOICE, the signal is eliminated and the receiver is used in the normal manner.

4.1.2.5.6. Band selector switch. Frequency range can be selected.

4.1.2.5.7. Tuning meter. Used to fine-tune the receiver when the function switch is at COMP or ADF. Maximum deflection of the needle to the right indicates the most accurate tuning of the receiver. Accurate refers to the bearing information and not necessarily to the audio signal reception.

4.1.3. Theory of Operation.

4.1.3.1. The ADF equipment uses two antennas known as the loop (directional) and sense (nondirectional) antennas. The operation of the low frequency receiver on a radio compass depends primarily upon the characteristics of the loop antenna. A loop-receiving antenna gives maximum reception when the plane of the loop is parallel to or in line with the direction of wave travel. As the loop is rotated from this position, volume gradually decreases, and it reaches a minimum when the plane of the loop is perpendicular to the direction of travel. This is the point of minimum reception and is referred to as the null. Further rotation causes the signal strength to increase gradually until the loop is parallel to the direction of the radio waves to the point of maximum reception.

4.1.3.2. The "null" property of the loop can be used to find the direction of the transmitting station if there is a sensing antenna to solve the ambiguity of the loop. The loop antenna alone can be used to locate a transmitting station, but the operator has no way of knowing whether the station is on a specific bearing or its reciprocal (one of two directions 180° apart). This is known as the 180° ambiguity of the loop. Only one null is received when a signal from a sensing antenna is superimposed on the signal from the loop antenna, thus indicating the direction of the station and eliminating the 180° ambiguity.

4.1.3.3. The loop antenna of the radio compass is automatically rotated to the null position (continuously positioning itself to remain perpendicular to the station) when signals are being received over both the loop and sensing antennas.

4.1.4 Classes of NDBs. NDBs are grouped into four classes. HH class beacons transmit with at least 2,000 watts of power and have a range of at least 75 miles. They are normally used for long over-water routes. H class beacons have a power output of from 50 to 1,999 watts and a range of up to 50 miles. MH class beacons are the most common type used in the US. They have a power output of less than 50 watts and a range of 25 miles. The fourth class of NDB, the compass locator, is part of the ILS and is discussed in paragraph 4.1.4.2. below.

4.1.4.1. Each of these beacon classes broadcasts a continuous Morse Code identifier, which is interrupted when there is a voice transmission such as a Transcribed Weather Broadcast (TWEB) on the frequency. If the station has no voice capability, the class designator is given a final "W" (for example, class MHW). On government en route charts the frequency will be underlined to show no voice capability.

4.1.4.2. The fourth class of NDB is the compass locator, which has a power output of less than 25 watts and a range of 15 miles. Compass locators are a part of the ILS and are usually collocated with the OMs and MMs. The class designator is LOM (Locator Outer Marker), and the identifier is the first two letters of the ILS identifier. For example, if the localizer identifier is I-SFO, the LOM identifier is SF. Compass locators located at the MM are known as Locator Middle Markers (LMM), and the identifier is the last two letters of the localizer identifier. In our previous example, the LMM identifier would be FO.

4.1.5. Automatic Direction Finding Errors. Although the ADF receiver is not limited to LOS reception, low and medium frequency radio beacons are subject to errors that affect the accuracy of the bearing received. Even when the ground facility has been positively identified and the set has been tuned accurately, the bearings received may not be correct. Some of the more common errors are described below.

4.1.5.1. Bank or Dip Error. This error is most predominant when the aircraft is at altitude close to the station. While the aircraft is banking, the bearing points down towards the station, providing an inaccurate reading. The error is greatest on nose and tail bearings when the bank is applied; it is least when the aircraft is in straight and level flight. Bank error is a significant factor during NDB approaches.

4.1.5.2. Precipitation Static. When the ADF is used as a low frequency receiver, precipitation static may make the reception noisy. This type of static can be reduced by putting static dischargers on the trailing edges of the wing. Areas of ice crystals may also cause the bearing pointer to fluctuate excessively or give erroneous indications.

4.1.5.3. Thunderstorm Effect. Radio waves are distorted by the electrical disturbances caused by thunderstorms. There may be erratic fluctuations of the bearing pointer in the direction of the thunderstorm. There may even be cases when the bearing pointer may home to the thunderstorm.

4.1.5.4. Weak Stations. When the bearing is taken from a station that is difficult to identify, remember to use caution. Interference from other stations may cause an erroneous bearing.

4.1.5.5. Night Effect. This effect is caused by reflection of radio waves by the ionosphere. The effect is most noticeable when the height of the ionosphere is changing at sunrise and sunset. The interference from the bouncing radio waves will cause the bearing pointer to fluctuate. The amount of interference depends largely on the frequency used and the type of antenna. The maximum night effect is on commercial broadcast stations operating near 1,000 kHz. Generally, the interference is slight within 30 miles of the station, but increases with distance from the station. Night effect can be reduced by increasing altitude, flying closer to the station, or tuning a station of a lower frequency or stronger signal. If the needle is fluctuating due to night effect, it may be necessary to interpolate the average of the fluctuations. It is also possible at night to receive signals from another station on the same frequency as the one you intend to use. For this reason and because the ADF does not have a failure flag or indicator, you must monitor the identifier during the approach.

4.1.5.6. Shoreline Effect. This error occurs when radio waves change direction crossing the shore line. It is possible to have errors of 40° in bearing. The maximum error is found when the bearing to or from the station is less than 30° to the shoreline.

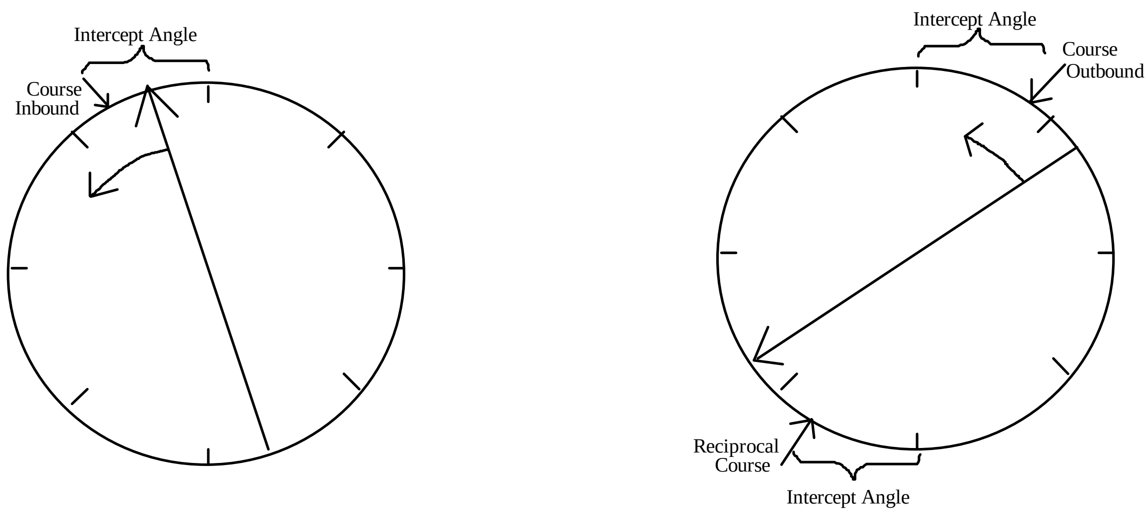
4.1.5.7. Mountain Effect. Mountains reflect radio waves, creating fluctuations of the bearing pointer. Sometimes the radio waves can be split or bent in the area of mountains, so be cautious when taking a bearing in mountainous regions.

4.1.6. ADF Courses. Remember, all the ADF does is point to the station. For example, your aircraft is headed 040° and the NDB is slightly in front of and to the left of the aircraft. The bearing to the NDB is 330°. Bearings are courses TO the NDB, so, this puts you southeast of the NDB. If your bearing pointer is on a compass card that shows aircraft heading, such as on an RMI or HSI, then you can read the courses directly off the compass card under the bearing pointer. The station is 70° left of the nose, but if we say that 0° is off the nose and count the degrees around a compass rose to the station, we get 290°. This is known as a relative bearing. If you do not have an RMI or HSI, or your compass card fails, then you would add your aircraft heading to the relative bearing to get the course TO the station. Courses FROM the station are read exactly the same way except that you use the tail of the bearing pointer. Where a published NDB bearing is used to define an intersection, it is always a bearing TO the NDB. On an approach procedure where an inbound and outbound bearing must be flown, both are published.

4.1.6.1. A CDI is incompatible with an ADF and its indications must be disregarded. However, the RMI/HSI bearing pointer indications are the same as a VOR/TACANs. The difference is that the ADF needle points to the station and shows the course because of the compass card movement, whereas a VOR/TACAN needle points to the course inbound and gives relative bearing by virtue of the compass card movement. This distinction is only important if the compass card fails. In which case, the ADF needle will give you correct relative bearing but a false course inbound, and the VOR/TACAN needle will give you a correct course inbound with a false relative bearing.

4.1.6.2. Intercepts. Course intercepts off of an RMI/HSI are fairly simple. Find the course on the compass card. If that course is TO the station, then you need to get the bearing pointer on that course. If the course is FROM the station, then you need to get the tail of bearing pointer on that course. Now, always remember that the head of the bearing pointer falls and the tail always rises (we'll discount winds). From there, it's just a matter of turning so that the bearing pointer is above a course inbound or the tail is below a course outbound. Your intercept angle is the difference between your heading and the course TO or FROM the station (see Figure 4.1.). If you don't have a tail for your bearing pointer and need to intercept a course outbound, use the reciprocal course and work in the bottom of the case as shown in Figure 4.1.

Figure 4.1. ADF Course Intercepts.



4.1.6.3. Maintaining Course. There are two golden rules to maintaining course with NDBs. The first one we already discussed. "Heads fall and tails rise" is what you need to know to correct back on course. The second is to never make a correction until you are sure you are off course. Since the ADF needle tends to swing a little bit, it's easy to start chasing it around. The key is to hold a rock solid heading until you are off course and then chose a new heading using the first rule.

4.1.7. Determining station passage.

4.1.7.1. Station passage is determined when the bearing pointer passes 90° to the inbound course. When established in an NDB holding pattern, subsequent station passage may be determined by using the first definite movement of the bearing pointer through the 45° index.

4.1.7.2. As the aircraft reaches the immediate proximity of the station at high altitude, it enters an area of signal confusion in which the bearing pointer becomes unsteady and erratic. The pointer may swing as much as 30° either side of the index at the top of the case. The needle oscillates, swings, and then eventually settles at the bottom of the case. This area increases with altitude. At higher altitudes, one to three minutes may elapse from the time the bearing pointer starts to rotate until it stabilizes at or near the bottom of the instrument case. Timing should begin at the instant the needle swings through 90°, regardless of further oscillations.

4.2. VHF Omni-Directional Range (VOR) System.

4.2.1. Introduction. The VOR is a radio facility used for air navigation. DME may be installed with a VOR facility. Since VOR transmitting equipment is in the VHF band, the signals are relatively free of atmospheric disturbances. VOR reception is limited to line-of-sight and the usable range varies according to the altitude of the aircraft and the class of the VOR station.

4.2.2. Transmission Principle. The transmission principle of the VOR is based on creating a phase difference between two signals. One of the signals, the reference phase, is omnidirectional and radiates from the station in a circular pattern. The phase of this signal is constant through 360°. The other signal, the variable phase, rotates uniformly at 1,800 RPM and its phase changes 1° for each degree change in azimuth around the VOR.

4.2.3. Establishing a Baseline. Magnetic North is used as the baseline for electronically measuring the phase relationship between the reference and variable phase signals. At Magnetic North, the signals are exactly in phase; but a phase difference exists at any other point around the station. This phase difference is measured electronically by the aircraft receiver and displayed on the aircraft instruments (radio magnetic indicator, course deviation indicator, horizontal situation indicator, etc.) as a magnetic bearing to the station.

4.2.4. Radials. The VOR provides an infinite number of courses which radiate from the station like the spokes from the hub of a wheel and are known as radials. It is possible to fly any one of these radials to or from a VOR.

4.2.5. TO and FROM Indications. Radials are identified by their magnetic bearing FROM the station. For example, with 180° set in the course selector window, a TO indication will appear, regardless of heading, when the aircraft is North of the line between 090° and 270°. A FROM indication appears when the aircraft is South of the line between 090° and 270°, and 180° is set in the course selector window. In the area along the 090° and 270° line, the signals will be ambiguous and result in a fluctuating TO/FROM indication. The fluctuation time will vary based on altitude and distance from the station. At 150 knots, 3,000 feet AGL, and 5 NM from the station, these fluctuations may last 50 seconds.

4.2.6. Transmission Characteristics. VORs are identified by automatic voice transmission which always verbally transmit the letters "V-O-R" following the station name or by Morse code. The voice transmission will have the verbal identification alternating with a Morse code identifier. Positive identification of a VOR is necessary to make sure you are navigating on the proper VOR and so Flight Service Stations (FSS) can make voice transmissions on various "remote" VOR facilities. If you hear "Klamath Area Radio" transmit a weather broadcast, you may be tuned to the Klamath VOR or one of the VORs remote from Klamath FSS. During periods of maintenance, the VOR may radiate a T-E-S-T code or the Morse code identifier may be removed.

4.2.7. VOR Radio Class Codes.

4.2.7.1. En route normal usable altitude and range limitations for various classes of VOR stations, based on interference-free signal reception, are specified in FLIP. The IFR en route airspace structure consists of airways or specified courses defined by VORs. Stations usable in the low altitude structure (below 18,000 feet MSL) are classified as (L) and (H) class VORs and are usable for at least 40 miles. (H) class stations are also usable to a distance of 100 miles above 14,500 feet and to 130 miles above 18,000 feet. The frequencies of most (L) and (H) class VORs are in the 112.0 to 118.0 range.

4.2.7.2. Terminal, class (T) VORs, are not usually part of the IFR en route navigation system. The (T) class VORs are usually located on the airport and are normally usable only within 25 NM up to 12,000 feet. Most (T) class VORs have a frequency range between 108.0 and 112.0, as do other VHF NAVAIDs such as localizers, Localizer-type Directional Aids (LDA), and Simplified Directional Facilities (SDF).

4.2.8. Operational Service Volume. In some cases the usable range of a VOR may be different from the standard service volume. A restriction over all or part of the station's broadcast area will be noted in the civilian Airport/Facility Directory, IFR En route Supplement, and Notice to Airmen (NOTAM).

4.2.9. Voice Communications. Most VORs have voice a communications capability and Flight Service uses VORs to talk to aircraft. If a VOR has no voice capability, its class designator will end in a "W" (for example, VORW). If a VOR is equipped with a continuous TWEB, it is designated with AB preceding the class designation (for example, ABVOR).

4.2.10. Inherent Error. VOR energy will reflect from some features of the Earth's surface. This results in an effect known as "scalloping," which is a smooth, rhythmic deviation of the cockpit indicators or a roughness that is a ragged, irregular deviation, normally for short time intervals. The effects will look similar to approaching station passage.

4.2.11. VOR Receiver Testing. There are several methods for testing the accuracy of a VOR indicator.

4.2.11.1. VOR Test Facility (VOT) Check. A VOT is a low-power (2 watt) VHF omnitest transmitter which permits the ground checking of aircraft VOR equipment without reference to a check radial. VOT emits an omnidirectional magnetic North (360°) radial, plus aural identification consisting of a series of dots or a continuous tone. It is monitored to a tolerance of ± 1°.

4.2.11.1.1. LOS reference to the VOT must be established prior to use because any intervening structure may induce a shielding effect and reduce signal strength.

4.2.11.1.2. Some VOT installations now also carry ATIS data.

4.2.11.1.3. The airborne use of a VOT is permitted, but is strictly limited to those areas and altitudes specifically authorized in the Airport/Facility Directory or appropriate supplement.

4.2.11.1.4. Aircraft equipment properly tuned to a VOT should have the CDI centered and the bearing pointer reading 0° with a FROM indication or 180° with a TO indication. The allowable tolerance is ±4°. If the VOR receiver operates an RMI, the needle will indicate 180° on any omnibearing selection.

4.2.11.2. Designated Ground Checkpoint. At certain airports, a circle is painted on the pavement, usually on the ramp or at the run-up area. The course to and from a designated VOR will be indicated. To use a designated ground checkpoint, park on the painted circle (your heading doesn't matter) and center the needle. The course selector window should read within 4° of the specified course. You can also check your DME against the published distance from the station to the checkpoint. Designated ground checkpoints are listed in the FAA Airport/Facility Directory.

4.2.11.3. Airborne Checkpoint. Airborne checkpoints consist of certified radials that should be received over specific points or landmarks while airborne in the immediate vicinity of the airport. The course selector window should read within 6° of the specified radial. Locations of airborne checkpoints can be found in the civilian Airport/Facility Directory and in FLIP Area Planning.

4.2.11.4. Dual VOR Check. You may test two VOR instruments against each other. Tune them to the same VOR and center the needles. They should read within 4° of each other. The dual VOR check is the least desirable since it might "pass" two wildly inaccurate instruments as long as they have similar errors. For example, if one instrument reads +7° and the other +10°, they pass. The dual VOR check will also fail two instruments that individually would pass a test. For example, if the VOT check shows one instrument + 3° and the other -3°, they are both good VOR instruments, but will fail the dual VOR check since they are 6° apart.

4.2.11.5. Self-Test. Many aircraft have VORs with a self-test function that provides an operational test of the system. The aircraft flight manual will discuss the specific procedures for your aircraft. The self-test does not, however, test the aircraft antennas. If the self-test checks within your aircraft's flight manual tolerances and you can receive the identification from the station, it is not necessary to test the VOR at a ground check point.

4.2.12 Common errors when using the VOR. Here are some common errors made when using VORs:

- Careless tuning and identifying of the station.
- Failure to properly check the accuracy of the VOR equipment on board the aircraft.
- Turning in the wrong direction during a maneuver. This is a common error until the pilot visualizes position instead of heading.
- Misinterpretation of station passage. On VOR receivers equipped without an ON/OFF flag, a voice communication on the VOR frequency will cause the same fluctuations as approaching station passage. VOR station passage occurs when the TO/FROM indicator makes the first positive change to FROM.
- Chasing the Course Deviation Indicator (CDI) which results in homing instead of tracking. Lack of attention to heading control and failure to make proper wind corrections make this a common error.

4.3. Tactical Air Navigation (TACAN) System.

4.3.1. Introduction. TACAN is a UHF omnidirectional NAVAID which provides continuous azimuth information in degrees from the station and slant range distance information up to 200 NM from the station, depending on aircraft altitude. Because TACAN ground equipment is compact and relatively easy to transport, it also provides for greater versatility in beacon installation and mobility than the VOR system.

4.3.2. Equipment and Transmission Principles. TACAN operates in the UHF (1060 megahertz (MHz)) frequency band. The system has a total of 126 two-way channels operating on a frequency range of 1,025 to 1,150 MHz air to ground. DME-associated ground-to-air frequencies are in the 962 to 1024 MHz and 1151 to 1213 MHz ranges. Channels are spaced at 1 MHz intervals in these bands. The TACAN can also have an X or Y setting to double the frequencies available. A difference in microsecond pulse length is the only difference in the X and Y settings. These settings will be used in a dense signal environment where it is possible to have duplicate frequencies. The TACAN frequency will be X unless the letter Y appears in parenthesis after the TACAN frequency.

4.3.3. Ground Equipment. This consists of a rotating type antenna for transmitting bearing information and a receiver-transmitter (transponder) for transmitting distance information. TACAN identifies aurally through international Morse code every 30 seconds. There is only one transmitter for bearing, DME information, and station identification. For this reason, the station identification is designed to operate less than continuously, and the aircraft equipment has an installed memory system (normally 3 seconds), which provides bearing information while the bearing signal is off the air during an identification.

4.3.3.1. Older, permanent TACAN ground stations are usually dual-transmitter equipped (one operating and one on standby) and fully monitored installations. These automatically switch to the standby transmitter when a malfunction occurs. New TACANs and many FAA systems are solid-state single transmitters. The new systems use a single transmitter because of the reliability of solid-state equipment. Mobile TACANs still use dual transmitters.

4.3.3.2. If you are using a TACAN and receive only bearing or only DME, there is a dual malfunction. First, bearing and DME are integral; TACANs cannot function properly without both systems operating. Second, the system that is supposed to detect this error has failed to knock the TACAN off the air. Use the TACAN only if it is providing both bearing and DME information. The ground monitor is located at the TACAN and it detects if the monitored radial shifts more than ±1°. There is an electronic NAVAID monitor system designed to "go into alarm" to indicate there is a problem with one of the NAVAIDs. The system continuously monitors the NAVAID equipment to detect power fluctuations, inaccurate signals, etc., and is normally positioned in the RAPCON. If there is no RAPCON, the monitor facility may be located in the tower. At FAA facilities, the remote monitor may be located in a FSS up to 100 miles away from the TACAN. Any time TACAN reception is suspect or bearing and/or distance breaks lock in flight, you can check on the status of the ground equipment by calling ATC.

4.3.4. Reporting Malfunctions.

4.3.4.1. When reporting a malfunction of the TACAN (or any NAVAID), the controller will ask a second aircraft for a report on the status of the TACAN. If the second aircraft reports no problems, you will be informed of this fact. If the second aircraft confirms the malfunction or if the second aircraft is absent, the controller will activate the standby equipment or request a report from the monitor facility. When a problem exists with a NAVAID, the monitor system will indicate there is a malfunction. If personnel working near the monitor have not reported a malfunction to the controller, the controller will ask them to confirm if a malfunction indication is showing. The status of the NAVAID will be reported to the aircrew reporting a problem.

4.3.4.2. It is possible to select a TACAN station and get erroneous DME and azimuth lock on because the station is undergoing maintenance or checkout. This can be detected by the absence of an identifier signal, so always listen for identification signals during flight.

4.3.5. Theory of operation.

4.3.5.1. Phase comparison of radio signals for bearing information is the operating principle of the TACAN system. It can be defined as the measurement of the time interval between the reception of two signals.

4.3.5.2. Two basic signals are produced by the rotation of the inner and outer reflectors of the central antenna. A 15 Hz signal is produced once during each rotation of the inner reflector. A 135 Hz signal is produced nine times with each rotation of the outer reflector. When the radio wave's maximum (lobe) of the 15 Hz signal passes through Magnetic East, a separate omnidirectional signal is transmitted. This is the main reference signal. When each of the nine lobes of the 135 Hz signal passes through magnetic east, nine additional omnidirectional signals are transmitted and designated auxiliary reference signals.

4.3.6. Measuring Aircraft Bearing. To determine the aircraft position in bearing from the station, a phase signal must be electronically measured. This is done between the main reference signal and 15 Hz signal. This time interval is converted to an angle, which isolates one of the nine 40° segments. The time interval between the reception of the auxiliary reference signal and the maximum of the 135 Hz signal is measured within that segment. This angular difference is converted into degrees magnetic and displayed on the TACAN bearing pointer. For practical purposes, there are 360 radials which are read off the "tail" of the bearing pointer. A 3-second memory circuit within the receiver maintains the last bearing should there be a loss of signal. Temporary obstruction of TACAN signals can occur in flight when aircraft fuselage, gear, external stores, or a wingman gets between the ground and the aircraft antenna.

4.3.7. Determining Distance. Distance is determined with TACAN equipment by measuring the elapsed time between transmission of interrogating pulses of the airborne set and reception of corresponding reply pulses from the ground station. The aircraft transmitter starts the process by sending out the distance interrogation pulse signals. Receipt of these signals by the ground station receiver triggers its transmitter, which sends out the distance reply pulse signals. These pulses require 12 microseconds round-trip travel time per NM of distance from the ground beacon. Since a large number of aircraft could be interrogating the same beacon, the airborne set must sort out only the pulses that are replies to its own interrogations. Interrogation pulses are transmitted on an irregular random basis by the airborne set, which then "searches" for replies synchronized to its own interrogations. If the signals are interrupted, a memory circuit maintains the indication on the range indicator for approximately 10 seconds to prevent the search operation from recurring. This range is accurate to within ± 600 feet plus 0.0002 percent (0.0002% equals 240 feet at 200 miles) of the distance being measured. There can be 100 simultaneous interrogations of the DME without saturating the TACAN. When more than 100 DME interrogations are received, the TACAN automatically ignores the weaker signals. The TACAN can handle an unlimited number of bearing interrogations.

4.3.8. The Cone of Confusion. Above the ground station, there is a cone of confusion above the NAVAID within which the equipment receives only distance information. The cone can vary from 60° to 110°, depending on the type of ground installation. The 90° cone shows that bearing information can be lost for a distance of 12 NM at 36,000 feet. For practical purposes, the DME reading may be considered the vertical distance over the station.

4.3.9. Station Passage. As the aircraft enters the cone of confusion the bearing pointer will break lock and begin to rotate. The track indicator and TO/FROM indicator may reflect the bearing pointer movement. If installed, the course warning flag will appear. The range indicator will continue to decrease until the aircraft is over the station; then it will begin to increase as the aircraft passes the station. As the aircraft leaves the cone of confusion, the bearing pointer will stabilize and the track indicator will resume its normal indication. Station passage is determined when the range indicator stops decreasing; that is, when it indicates the approximate aircraft altitude above the station in NM. For example, the range indicator in an aircraft at 30,000 feet above a station will stop decreasing at approximately 5 NM.

4.3.10. Usable Range. Bearing and distance information is subject to LOS restrictions. At low altitudes, the curvature of the earth restricts the distance from which the signal can be received from the ground station. Range and distance relationships are as follows: 1,000 feet = 40 NM, 5,000 feet = 85 NM, 10,000 feet = 120 NM, 20,000 feet = 65 NM.

4.3.11. TACAN Characteristics and Errors. Since TACAN bearing and distance signals are subject to LOS restrictions, the rotating bearing pointer and DME indicator break lock if these signals are obstructed. Aircraft receiver memory circuits prevent unlocking when signals are obstructed for short periods (10 seconds DME and 3 seconds bearing). When break lock does occur, the equipment will stay unlocked until the obstruction is removed and the search cycle is completed. Watch for break lock during procedure or penetration turns or during other maneuvers that cause the aircraft antenna to be obstructed for more than 3 to 10 seconds.

4.3.11.1. Distance Anomalies. Slight oscillations up to 1/4 of a mile for range indicators may occur because of the pulse generated by the transmitter and receiver functions. When a usable signal is lost, the memory circuit will maintain the indicated range for about 10 seconds. Then it will unlock, unless usable signals are regained.

4.3.11.2. Azimuth Error Lock On.

4.3.11.2.1. The construction of the TACAN ground antenna (one main and eight auxiliary reference pulses), makes it possible to have 40° azimuth error lock on. When the airborne receiver is working correctly, these pulses lock onto the airborne equipment with the main reference at 90°. When the airborne receiver is weak, the main reference pulse may "slide over," miss the 90° slot, and lock on at one of the auxiliary positions. When this occurs, azimuth indications will be 40° (or some multiple of 40°) in error. Should this happen, rechanneling the receiver to deliberately make it unlock may help the set lock on properly. When other means of geographic fixing are available, use them to confirm suspected TACAN errors.

4.3.11.2.2. False or incorrect lock-on indications in the aircraft can be caused by misalignment or excessive wear of the airborne crystal selector assembly. Selection of a TACAN channel activates a drum-and-wiper arrangement in the aircraft receiver. The drum rotates until the wiper contacts the appropriate crystal on the drum. These crystal contact points are very small (the size of the head of a pin) and close together. Wear of this assembly or other misalignment can cause the wiper to miss the proper crystal and either contact the wrong one, resulting in the wrong TACAN transmitter being tuned in, or miss it entirely, resulting in a constant unlock. Should this occur, rechanneling from the selected channel number and back (preferably from the opposite direction to the original setting) will sometimes give the correct selection.

4.3.11.3. Co-channel Interference. Co-channel interference occurs when an aircraft is in a position to receive TACAN signals from more than one ground station on the same frequency. Normally it occurs only at high altitudes when distance separation between like frequencies is inadequate. The aircraft equipment may lock onto the wrong TACAN. You will not get information from both TACANs simultaneously. The only way to identify which TACAN you have is through the Morse code identifier. Co-channel interference is not a malfunction of either air or ground equipment. It is a result of ground equipment location and aircraft position.

4.3.11.4. Dropout. At the extreme LOS range, there is a loss of signal because of the lobe shape of the radiation patterns. This is called dropout.

4.3.12. Precautions to Prevent Navigation Errors.

- Always use Morse code to identify any NAVAID station and monitor it during flight. Monitor means having the NAVAID selected on the interphone panel with the volume up high enough to detect problems with the identification.
- Always use all suitable navigational equipment aboard the aircraft, and cross-check heading and bearing information.
- Never overfly an Estimated Time of Arrival (ETA) without carefully cross-checking the NAVAIDs and ground checkpoints.
- Check NOTAMs and FLIP before flight for possible malfunctions or limitations on NAVAIDs to be used.
- Discontinue use of any suspect NAVAID and, if necessary, confirm aircraft position with radar or other equipment.

4.3.13. TACAN Approaches.

4.3.13.1. With range information available, many different types of penetrations are depicted on the approach charts. Some TACAN approaches are relatively simple and involve only a straight-in flight path along a radial. Others require extensive planning and may involve intercepting an arc from a radial, a radial from an arc, or any combination of the above to arrive at the FAF.

4.3.13.2. A limited number of VOR instrument approaches based on a VORTAC facility have been approved for use by TACAN-equipped aircraft. These approaches are identified by the term "or TACAN" printed adjacent to the name of the procedure (for example, VOR or TACAN RWY 17) or by the letters "(TAC)" printed after the name of the approach. Approaches designated VOR/DME are executed by aircraft using VOR with DME. DME is required unless alternate means, such as crossing radials or markers, can be used to identify the DME fixes. If an approach listed as VOR is based on a VORTAC and there is no mention of TACAN in the approach name, TACAN cannot be used to fly the approach. In addition, if no DME fixes are published, you cannot invent them on your own. This is because the approach has not been designed for DME and your invented DME fixes have not been flight inspected for accuracy or reception.

4.4. Instrument Landing System (ILS).

4.4.1. Introduction. ILS is a precision approach system which provides course and glideslope guidance to the pilot. It consists of a highly directional localizer (course) and glideslope transmitter with associated marker beacons, compass locators, and, at some sites, DME. The system is automatically monitored and provides changeover to a standby localizer or glideslope transmitter when the main system malfunctions.

4.4.2. ILS Categories. ILS is classified by category according to the performance capability of the ground equipment. Category I ILS equipment provides guidance information down to a Decision Height (DH) of not less than 200 feet and a visibility of 1/2 statute mile (a Runway Visual Range (RVR) of 2,400 feet). Improved equipment (airborne and ground) and certifications provide for Category II ILS approaches to DH of not less than 100 feet and an RVR of 1,200 feet. There are three levels of Category III ILS. Category IIIa ILS provides for an approach with no DH, but an RVR of at least 700 feet. Category IIIb ILS also has no DH, but an RVR of 150 feet. Category IIIc ILS essentially is a zero/zero approach with no DH or RVR requirement.

4.4.3. Components.

- **Localizer Transmitter.** The localizer transmitter (paragraph 4.4.4) provides lateral guidance and is usually located at the far end of the runway so that its course overlies the runway centerline.
- **Glideslope Transmitter.** The glideslope transmitter (paragraph 4.4.6) sits about 1,000 feet from the runway threshold so the Threshold Crossing Height (TCH) of the glideslope is approximately 50 feet. An aircraft on glideslope and not altering its descent angle after passing the glideslope transmitter will touch down abeam of the glideslope antenna. The TCH is the altitude the aircraft receiver antenna crosses the threshold, not the aircraft's landing gear which will cross the threshold at a lower altitude.
- **Outer Marker (OM).** If an Outer Marker (OM) is installed, it is approximately 5 miles from the runway just about where an aircraft at the glideslope intercept altitude will intercept the glideslope.
- **Middle Marker (MM).** If a Middle Marker (MM) is installed, it is approximately 1/2 mile from the threshold just about where an airplane on the glideslope reaches Category I ILS DH.
- **Inner Marker (IM).** An Inner Marker (IM) is located at the Category II ILS DH.
- **Compass Locator.** There may be a low-power NDB, known as a compass locator, at the OM or MM. A low power NDB is either a Locator Outer Marker (LOM) or Locator Middle Marker (LMM). Even though the LOM and LMM are NDBs, they are still capable of being received by the marker beacon equipment onboard your aircraft.
- **Approach Lighting System (ALS).** An approach lighting system (ALS) is almost always associated with an ILS. An ALS offers a wide variety of lighting and can extend as far as 1/2 mile from the runway. It can be seen by the pilot in all but the worst weather.

4.4.4. Localizer Transmitter. The localizer transmitter is normally located about 1,000 feet beyond the departure end of the ILS runway. ILS localizer transmitters use the odd-decimal VHF frequencies from 108.10 to 111.95 (108.7 for example). The antenna is in line with the runway centerline and radiates the 90-cycle and 150-cycle signal patterns on opposite sides of the extended runway centerline. The 150-cycle signal is on the right when looking at the runway from the OM; and the 90-cycle signal is on the left. The course is formed along the extended runway centerline (toward OM) where the signals overlap and are of equal strength. This course is referred to as the front course.

NOTE: Some aircraft's ILS equipment may not be capable of receiving the .05 MHz frequency even though the VOR equipment will receive this signal. In this case, the aircrew will be unable to receive the ILS signal and cannot fly the ILS approach. These .05 MHz frequencies are designed to eliminate a single frequency used for ILS equipment at both ends of a runway when frequency congestion is a problem. Consult your aircraft technical order to determine if you are frequency limited.

4.4.4.1. Morse Code and Communication Capabilities. The Morse Code identifier consists of four letters, the first of which is always an "I." ATC has voice capability on some of these frequencies. An underlined frequency indicates the transmitter has no voice capability. If your communications receiver fails, it pays to keep the volume up on the NAVAID. You can respond to ARTCC transmissions on the VHF NAVAID with the IDENT button on your transponder. Localizer frequencies are received by the same equipment as VOR signals; and although different circuits are used internally to decode the course signal, the CDI reacts to them similarly.

4.4.4.2. Localizer Width. Localizer width varies from 3° to 6°, depending on the distance of the transmitter from the landing threshold. The exact width is chosen to produce a signal ± 350 feet either side of centerline at the threshold. A full scale CDI deflection indicates 1.5° to 3° off course, which means the localizer is approximately four times as sensitive as a VOR signal. On an instrument with two dots each side of center, one dot represents approximately 800 feet displacement from centerline at the OM, and approximately 250 feet at the MM (based on a localizer width of 5°, a runway length of 8,000 feet, and touchdown point 1,000 feet from threshold).

4.4.4.3. Localizer Alignment. The localizer is aligned to within 3° of the runway centerline and is normally lined up on the extended runway centerline. If the localizer angles 1° or 2° from the runway centerline, it is shown on the approach plate plan view as an "offset localizer" and a note is printed on the profile view. Although slightly offset, the approach is still considered a straight-in.

4.4.4.4. Back Course Localizer. Most localizer transmitters also provide a signal pattern around the runway so course signals also overlap in the opposite direction forming a back course. Every localizer antenna puts out a back course signal unless it is shielded.

- **Identification is Critical.** It is critical to identify the localizer you are flying, using Morse code to prevent flying the wrong localizer. In areas where there is a dense signal environment, there may be only one localizer frequency used for both ends of a runway. There have been cases during runway change where the localizer antenna was accidentally not switched and crews attempted to fly a back course localizer. The only way to tell which localizer is transmitting is to identify the separate Morse code identifiers for each runway; simply listening for dots and dashes doesn't work. Back-course localizer IAPs are often published for civilian airfields and, on occasion, military airfields.
- **Disregard Glideslope Indications.** Disregard all glideslope signal indications when making a back course approach unless a usable glideslope is specified for that approach. Do not fly back-courses other than those published for approach use.
- **CDI Indications.** When flying inbound on the back course the CDI is not directional unless the published front course for the ILS is placed in the course select window of an HSI. Even in this case, the command bars of a flight director are not directional without reverse sensing. However, some aircraft ILS equipment includes reverse sensing capability. Consult your aircraft flight manual for system specific guidance.

4.4.5. Caution Regarding the Use of ILS Localizers. Localizers are subject to reflection from terrain, buildings, vehicles, and aircraft (on the ground or in the air). These reflections may cause course bends or scallops and/or roughness. A bend will not be noticeable from the cockpit because the course indications will appear normal. Scallops are smooth rhythmic deviations of the localizer course. Roughness is ragged, irregular deviations of the localizer course. Scallops and roughness may both occur during an approach. The frequency of these deviations are not flyable, and the pilot must "average out" the deviations to obtain a flyable course. A front course localizer has an on-course zone which is aligned with the extended runway centerline and monitored to a tolerance of approximately ± 1/4°. Ideally, it is 5° wide--2 1/2° on either side of centerline. This example equates to an 8,000-foot runway. A back course localizer has an on-course zone which is monitored and flight checked to wider tolerances. It may be from 3° to 6° wide depending on the particular installation. The ILS localizer and glideslope signal may be distorted when vehicles or aircraft are operated near the localizer or glideslope antennas. ILS critical areas are established to prevent these distortions from happening.

4.4.5.1. ILS Critical Area.

4.4.5.1.1. Non-Air Force Airfields. When conditions are reported less than 800-foot ceiling and/or visibility is less than 2 miles, non-Air Force controllers will not authorize aircraft or vehicles to operate inside the critical area while an aircraft is inside the ILS OM (or fix used in lieu of the OM). Operations inside the critical area are allowed if the aircraft has reported the airfield in sight and is circling or sidestepping to land on a runway other than the ILS runway.

4.4.5.1.2 Air Force Airfields. No critical area protection is required when the ceiling is at or above 800 feet and/or visibility is 2 miles or more. When the reported ceiling is less than 800 feet and/or visibility is less than 2 miles, aircraft larger than fighter type or size are restricted from proceeding beyond the instrument hold line while an aircraft flying an ILS approach is inside the FAF. When the reported ceiling is less than 200 feet or reported visibility less than 1/2 mile (RVR 2400), all aircraft are restricted from proceeding beyond the instrument hold line while an aircraft flying an ILS approach is inside the FAF.

4.4.5.1.3. If an arriving aircraft advises the tower that an AUTOLAND or COUPLED approach will be flown, an advisory will be given when another vehicle or aircraft is in or over the critical area while inside the ILS MM or 1 NM from touchdown if there is no MM.

4.4.5.1.4. Aircraft holding below 5,000 feet between the OM and the airport may cause localizer signal variations for aircraft conducting ILS approaches. To prevent this, holding in this area is not authorized when the ceiling is less than 800 feet and/or the visibility less than 2 miles.

4.4.5.1.5. Pilots must be aware that vehicles not subject to ATC control may cause momentary deviations to the ILS course or glideslope signals. Critical areas are not monitored at uncontrolled airfields or at controlled airfields where the weather or visibility conditions are above those requiring protective measures. Aircraft conducting AUTOLAND or COUPLED approaches must be especially careful to monitor equipment in these situations because other aircraft may cause momentary deviations during landing or go-arounds.

4.4.5.2. Limits. Flight inspection regularly confirms the coverage and validity of ILS localizer signals within 35° either side of a front course approach path to a distance of 10 NM and through 10° either side of a front course approach path to a distance of 18 NM. However, false or erratic ILS indications may be received beyond these limits. The ground monitoring system continuously monitors the equipment and should detect any condition that would cause lack of signal up to 18 NM or erroneous instrument indications within this area. An expanded service volume can be established for the localizer or glideslope.

4.4.5.3. False Courses or Low Clearances. It has been found that terrain or failure of certain elements of multielement localizer antennae may cause false courses or low clearances within 35° of the front or back course centerline of a localizer without being detected by the localizer monitoring system (see note). This situation is being addressed on a priority basis. In the interim, pilots are advised that it is essential to confirm the localizer on-course indication by referring to aircraft heading and NAVAIDs (such as an ADF bearing from the LOM) before commencing final descent. Any abnormal indications experienced within 35° of the published front or back course centerline of an ILS localizer should be reported to the appropriate ATC facility.

NOTE: A low clearance is a less than full scale deflection of the CDI at a position where a full scale deflection should be displayed.

4.4.5.4. Bend in the Glide path. A UHF glide path is subject to reflection from surface irregularities, vegetation, and other aircraft. This causes a bending of the glide path which will probably not be noticeable.

4.4.6. Glideslope Transmitter.

4.4.6.1 General Description. The glideslope transmitter is located approximately 750 to 1,250 feet down the runway from the approach end and 250 to 650 feet from the centerline. Like the localizer transmitter, 90 and 150 Hz signal patterns are transmitted to form a glideslope. The 150 Hz signal is below the glideslope; the 90 Hz signal is above it. The area of equal strength forms the glideslope. These signals are radiated out the front course only. The glideslope normally is set at an angle of 2 1/2° to 3° so it intersects the MM, where installed, near 200 feet and the OM, where installed, near 1,400 feet above the runway elevation. The glideslope envelope extends 0.7° above and below this angle. The glideslope has a usable range of 10 miles (measured from the glideslope antenna) unless an expanded service volume is established. Glideslope angles are monitored to a tolerance of 7.5 percent of the glideslope angle.

4.4.6.2. Glideslope Frequencies. Glideslope transmitters operate in the 329.15 and 335.0 MHz UHF frequency band and are paired to specific localizer frequencies. In most aircraft, the glideslope receiver is automatically tuned when the localizer frequency is selected. Glideslope transmitters do not emit identification signals and warning flags are the only means of checking the reliability of glideslope signals.

4.4.7. ILS DME. In some cases, ILS DME is provided. If your DME is manually tuned, you will have to set it to the ILS DME frequency. The DME ground beacon is normally located at the glideslope transmitter site, effectively providing distance to touchdown information.

4.4.8. Marker Beacons. Marker beacons are very low-powered 75 MHz transmitters located along the ILS final approach course to "mark" a specific position. Normally, two marker beacons are used for this purpose, and they are depicted on the terminal chart by the letters OM and MM. An additional beacon called an IM may also be installed for Category II and Category III ILS. The beacons are identified in the aircraft visually (marker beacon light) and/or aurally depending on aircraft equipment. The reception area of the aural signal is larger than the visual signal. Marker beacons are not installed for navigation purposes, but to merely indicate a fix on the localizer course.

4.4.8.1. Outer Marker (OM). The OM normally is located 4 to 7 miles from the end of the runway. OM identification consists of continuous dashes. Aurally, the dashes are comparatively low-pitched (400 Hz). The OM actuates a blue marker beacon light. Normal width of this signal is 1,350 feet to 2,650 feet, which means the light will flash for 7 to 13 seconds at 120 knots GS. The published altitude at the OM is what the altimeter should indicate when the aircraft is over the marker and on the glideslope; however, there are no specific limits. The OM altitude may also be the procedure turn or glideslope interception altitude. You can plan to use the OM as the sole means of identifying the FAF, if required.

4.4.8.2. Middle Marker (MM). The MM is located approximately 3,500 feet from the runway and is identified by alternating dots and dashes. The aural signal is comparatively high pitched (1,300 Hz) and is easily distinguished from the OM signal. The MM actuates an amber marker beacon light. The normal width of this signal is 675 to 1,325 feet, which means the light will flash for 3 to 7 seconds at 120 knots GS. Category I published minimums are normally reached at or near the MM. The MM may not be used as the sole method of identifying the MAP. Very few aircraft in the Air Force inventory can preflight the MM and none have a device onboard that will tell the pilot the MM system no longer functions. Therefore, since your first indication that the system did not work properly may be an abrupt encounter with the ground, you cannot count on the MM as your sole means of determining your MAP.

4.4.8.3. Inner Marker. Where installed, the IM will indicate a point at which an aircraft is at a designated (normally Category II) DH on the glideslope. The IM is an integral part of the Category II and Category III ILSs. The IM is modulated at 3000 Hz and identified with continuous dots keyed at the rate of six dots per second. The normal width of this signal is 340 to 660 feet, which means the light will flash for 2 to 3 seconds at 120 knots GS.

4.4.8.4. Back Marker (BM). A BM is located on a back course 3 to 5 NM back from the runway threshold and is identified by 6 dots per second. It modulates at an audio frequency of 400 Hz per second (low pitched) and actuates a blue marker beacon light. At some locations the BM may be supplanted by a "fix" intersection composed of the localizer course and a radial from a VOR or a bearing from a nondirectional beacon. The BM is used to mark the FAF on a published back course localizer.

4.4.9 Compass Locators. If installed, compass locators are placed at the marker beacon sites (usually only at the OM) as aids to navigation around the ILS. They are low powered, nondirectional radio beacons operating between 200 and 415

KHz with a reliable reception range of at least 15 NM. However, higher powered, low-frequency nondirectional radio beacons may be collocated with the marker beacons and used as compass locators. These generally carry TWEB information.

4.4.9.1. Approach Charts. On the approach chart, the radio data information box for the compass locator is broken at the top by the letters "LOM" or "LMM." The frequency and the identification of the facility are within the box.

4.4.9.2. Compass Locator Identifiers. The locator identification consists of two letters. When installed at the OM it will normally transmit the first two letters of the three-letter ILS localizer identification. If installed at the MM, it will transmit the last two letters. For example, with an ILS localizer identified by the letters "I-FAT," the compass locator identification at the outer marker is "FA" and at the MM is "AT." On the profile view of the approach chart, the locators are depicted by the letters LOM or LMM.

4.4.9.3. Maintenance. During periods of routine or emergency maintenance, the coded identification (or code and voice where applicable) will be removed from ILS localizers, but not from NDB compass locators or 75 MHz marker beacons. If you simply listen for dots and dashes as a means of identifying the NAVAID, the NDB compass locator could mislead you into believing the system is functioning properly when maintenance has made the signal unreliable.

4.4.10. ILS Procedures. Descriptions of courses, altitudes, frequencies, etc., for planning an ILS and transitioning to it from other NAVAIDs is found in the terminal FLIP. The approach should be considered in its entirety from en route transition through landing or missed approach. Use the FLIP documents, such as the en route charts, IAPs, and the IFR En Route Supplement, for planning.

4.4.10.1. Length of the ILS "Feather." When reviewing FLIP publications for ILS information, remember that the length of the ILS feather on an IAP means nothing. It does not tell you where the localizer is flight checked to nor does it tell you where to intercept the localizer course. As of right now, the feathers on the en route charts that depicted airfields with ILS approaches have been deleted from those charts.

4.4.10.2. Tuning the ILS Equipment. Tune the ILS receiver and identify and monitor the localizer identification signal as soon as possible during the transition procedure. The course and glideslope are reliable only when their warning flags are not displayed, the localizer identifier is received and properly identified using Morse code, and the aircraft is within the usable range of the equipment. The localizer is considered reliable within 18 NM miles of the transmitter and within 10° of the course centerline unless a transition point is depicted at another distance, which may be more or less than 18 NM. The glideslope interception point and altitude are designated on the terminal chart. The glideslope is considered reliable within 10 NM miles of the transmitter provided the aircraft is on the localizer course.

4.4.10.3. Radar Vectors. When being radar vectored to an ILS final, retain radar service until established at a point where you can transition to the published procedure. The controller should provide vector headings to within 30° of the localizer course, at least 2 miles from the glideslope intercept point, and at an altitude below the glideslope. When the controller issues the final vector, altitude, and clearance for the approach, you must know your position in relation to the airfield. If the aircraft is at a range beyond the coverage of the approach chart, maintain the last assigned ATC altitude until established on a published segment of the approach. "Published segment" means the course, radial, localizer, as appropriate, and the altitude for that segment of the approach. You must be complying with both published course guidance and altitudes to be established on a published segment of the approach. The localizer course may be flown outside of the 18 NM flight-check distance if the instrument procedure depicts a greater distance or radar service is provided. If the controller clears you to intercept a localizer course, regardless of the distance from the antenna, radar service is being provided and you are expected to intercept the localizer. Query the controller if you have any doubt concerning position or altitude clearance. Use radar monitoring service when available as an additional source of information.

4.4.10.4. Intercepting the Localizer. Before localizer interception, set the published front course in the course selector window so that the aircraft heading/localizer relationship is displayed on the CDI. The transition may require a large turn onto the localizer course; for example, a teardrop penetration or procedure turn. If the CDI indicates full scale deflection (course deviation 2 1/2° or greater) during the latter portion of the turn, roll out with an intercept angle that will ensure localizer interception prior to the glideslope intercept point. Normally a 30° to 45° intercept is sufficient; however, GS, distance from the localizer course, and FAF location may require another intercept angle.

4.4.10.5. Course Deviation Indicator. When the localizer is intercepted, maintain the published heading until first movement of the CDI. The rate of CDI movement will aid in estimating the force and direction of the wind. Heading corrections should be sufficient to stop the CDI movement and return the aircraft to course. After returning to course, apply the drift correction necessary to keep the CDI centered. Heading corrections should be reduced as the aircraft continues inbound (increments of 5° or less are usually sufficient). Maintain the glideslope interception altitude, configure the aircraft for landing, and establish the final approach airspeed before reaching the GSI point. Do not descend below glideslope interception altitude if the CDI indicates full scale deflection.

4.4.10.6. Glideslope Intercept (GSI). As the GSI moves downward from its upper limits, prepare to intercept the glideslope. Slightly before the GSI reaches the center position, establish a pitch attitude on the attitude indicator and a power setting that will result in the vertical velocity and airspeed required to maintain the glide path. The amount of pitch change required will depend on the aircraft GS and the glideslope angle. One technique that may be used when intercepting the glideslope (if the final approach airspeed and configuration have been established) is to change the pitch attitude on the attitude indicator the same number of degrees as the glideslope angle, normally 2 1/2° to 3°. The glideslope facility provides a path which flares from 18 to 27 feet above the runway due to signal reflections. Therefore, the glide path should not be expected to provide complete guidance to a touchdown point on the runway.

4.4.10.6.1. Pitch corrections.

4.4.10.6.1.1. Corrections are made using coordinated pitch and power changes. Normally pitch changes should result in vertical velocity changes of less than 300 feet/MIN. A 1° pitch change on the attitude indicator is usually a sufficient amount of correction to achieve a vertical velocity change of 200 to 300 feet/MIN for between 120 and 180 knots GS.

4.4.10.6.1.2. The size of the course and glideslope envelope narrows progressively throughout the approach. Therefore, the size of the pitch and bank corrections should be gradually reduced as the distance to touchdown decreases. Do not attempt to fly the final approach with full scale deflection on the CDI or GSI because obstruction clearance will not be assured.

4.4.10.6.2. Aircraft control. When flying an ILS approach the most common tendency is to "fly" the CDI and GSI. An ILS approach is a basic instrument maneuver similar to a radar approach. Immediate and smooth corrections should be made on the control instruments based on aircraft and flight path performance indications. The importance of precise aircraft control cannot be overemphasized. If a flight director is unavailable onboard your aircraft, assess drift early and establish a heading that will maintain track. Small heading corrections to maintain track are important in the final approach stage. Make these corrections with reference to the aircraft compass because the CDI gives only the aircraft position relative to the inbound track. "Chasing the CDI" is a sign of poor basic instrument flying. If the aircraft drifts off the localizer, causing the CDI to move away from the center, make a correction towards the CDI using the aircraft compass to regain the localizer. Then select a new heading that includes an allowance for drift.

4.4.10.6.3. Decision Height (DH). The most critical period of the approach occurs while you are busy maintaining course, glide path, and airspeed and are approaching the published DH. Ensure the altimeter is being included in the cross-check. The DH is the lowest altitude at which a missed approach will be initiated if sufficient visual reference with the runway environment has not been established. Perform the missed approach when at DH and visual reference with the runway environment is insufficient to complete the landing (runway or runway and approach lights), when instructed by the controlling agency, or when a safe landing is not possible.

NOTE: If the course warning flag is displayed during the final approach, initiate the missed approach procedure. If the glideslope warning flag is displayed, fly the approach no lower than the published localizer-only altitude or, if not published, no lower than circling minimum altitude for the aircraft category. A localizer-only approach is planned for and flown as a non-precision approach.

4.4.11. Use of Flight Directors During ILS Approaches. In addition to the information displayed by a course indicator system, the flight director provides computed pitch and bank steering commands for intercepting the localizer course and flying the final approach. This section will give you a basic understanding of flight director functions during ILS approaches; your aircraft flight manual will give specific guidance on the operation of your ILS equipment. Two modes of operation, intercept and final approach, may be used during an ILS approach. These two modes are referred to by various names, ILS, localizer, ILS approach, etc.

4.4.11.1. Intercept Mode.

4.4.11.1.1. The intercept mode is used for initial intercept of the localizer. When this mode is selected, the bank guidance is displayed. Flying the bank guidance should intercept the published localizer front course. The bank guidance may command up to a 45° angle of intercept to the localizer front course without regard to the location of the GSI point. Some flight directors do not correct bank steering commands for wind drift in this mode, in which case the intercept may have to be made disregarding the bank steering commands.

4.4.11.1.2. Before following the intercept mode commands, aircraft intercept heading should be within 90° or less of the front course to ensure a turn in the shorter direction. The aircraft must be positioned by use of other NAVAIDs or radar vectors to ensure localizer course interception prior to the GSI.

4.4.11.2.1. Final approach mode. The final approach mode is selected, manually or automatically, when the aircraft is established inbound on the localizer course. Restrictions for manual selection of the final approach may vary with flight directors. Some systems allow intercepts up to 90° while others may restrict operators to less than 15° of intercept and CDI within one dot of center. See your aircraft flight manual for systems specific operating instructions. When the final approach mode is selected, both pitch and bank guidance may be displayed. With automatic glideslope switching, the pitch guidance will not appear until near glideslope. Normally, bank steering commands are automatically corrected for wind drift in this mode.

4.4.12. Front course approach.

4.4.12.1. Transitioning to an ILS. This approach is performed by maneuvering the aircraft as depicted in the published terminal IAP or by radar vector to intercept the localizer course inbound. Analyze the entire approach procedure, landing environment, and missed approach procedures before beginning the approach, preferably on mission planning day. Tune the ILS as soon as practical during the transition. Set the published localizer front course in the course selector window. Position the flight director switches for localizer interception. The bank guidance will come into view. If any other course is set in the course selector window, the bank guidance will not command a correct intercept and the HSI will not reflect the actual aircraft/localizer course relationship. Use any available navigational facilities (TACAN for example), to aid in remaining position oriented to the localizer and glideslope intercept point.

4.4.12.2. Transitioning to the Localizer. When the aircraft is properly positioned and its heading is within flight manual tolerances, bank the aircraft to center the bank guidance. Properly flown bank guidance will intercept the localizer front course in a no-wind condition. When established inbound on course, select the final approach mode. The pitch steering command will come into view, and bank steering signals will be corrected for wind drift. Some aircraft select final approach mode when established on course; and, with automatic glideslope switching, the pitch steering bar will stay out of view until near the glideslope intercept point. Keep the bank command centered and monitor the CDI.

4.4.12.3. Intercepting the Glideslope.

4.4.12.3.1. Disregard the pitch steering command and maintain glideslope interception altitude, published or assigned, until reaching the GSI point. Establish the aircraft final approach configuration and airspeed in accordance with the aircraft flight manual. Do not descend below glideslope interception altitude if the CDI indicates full scale deflection.

4.4.12.3.2. The GSI will move from the upper limits of the glideslope deviation scale toward center as the aircraft approaches the glideslope intercept point. When the GSI approaches an on-glideslope indication, adjust aircraft pitch to follow the steering command. Control power to maintain final approach airspeed. Call the controlling agency at the FAF (OM, compass locator, DME, radar, or other approved compatible radio fix) according to position reports required by the FIH. During the remainder of the approach, control aircraft pitch and bank attitude to follow the steering commands. Monitor flight path and aircraft performance instruments to ensure that the desired flight path is being flown and aircraft performance is within acceptable limits. A common and dangerous error when flying an ILS on the flight director is to concentrate on the steering bars and ignore flight path (raw data) and aircraft performance instruments. Failure of the flight director computer may not be accompanied by the appearance of warning flags. Steering commands should always be correlated with flight path raw data (CDI and GSI) and aircraft performance instruments.

4.4.13. Localizer Approaches. Localizer-only approaches are planned and flown as non-precision approaches. If the approach is based on timing, it's important that the aircraft is configured and on final approach speed prior to the FAF and the timing is commenced at the FAF. There are also localizer-only approaches that use DME as the MAP. Execute a missed approach when you have has reached the MAP (timing, DME, or MM) and the runway environment is not in sight or a safe landing is not possible.

4.4.14. Localizer Back Course Approach. This is a non-precision approach since glideslope information is not provided. To maintain the proper aircraft heading/localizer course relationship, set the published front course in the course selector window. When inbound on the back course, the course arrow will be at the bottom of the HSI. The CDI will now be directional. Back course approaches are flown using techniques similar to those for localizer approaches. Since the localizer antenna will normally be on the approach end of the runway, the CDI will be more sensitive than a front course localizer as you approach the runway. The flight director can not be used, unless it provides a back course localizer mode, since the steering information is reversed.

4.4.15. Localizer-Type Directional Aid (LDA). This is of comparable use and accuracy to a localizer, but is not part of a complete ILS system. The LDA course usually provides a more precise approach course than the Simplified Directional Facility (SDF) does (paragraph 4.4.16).

4.4.15.1. Approach Alignment. The most important factor to remember about the LDA is that it does not line up with the runway. It is just an ILS or localizer offset more than 3°. Straight-in minimums may be published if the LDA alignment with the runway does not exceed 30°. Circling minimums are published when this alignment exceeds 30°. Although rare, there are LDAs that do include a glideslope. They contain a bold typed note signifying the presence of a usable glideslope.

4.4.15.2. ICAO LDA. You may see ICAO approaches that list the approach as an "IGS," an Instrument Guidance System. Essentially, this is the ICAO version of the US LDA and uses the same procedures and data.

4.4.16. Simplified Directional Facility (SDF). This facility provides a final approach course similar to that of the ILS localizer and the LDA. A SDF approach does not have glideslope capability.

4.4.16.1. Frequencies. The SDF transmits signals within the 108.10 to 111.95 frequency range.

4.4.16.2. Approaches. The approach techniques and procedures used on an SDF instrument approach are essentially the same as those used on a normal localizer approach. However, the SDF course may not be aligned with the runway and the course is normally wider. Which results in a less precise approach. The SDF signal width is fixed at either 6° or 12° as necessary to provide for maximum flyability and optimum course quality.

4.4.16.3. Limits. Usable off-course indications are limited to 35° on either side of the course centerline. Any instrument indications received beyond this 35° limit must be disregarded.

4.4.16.4. Approach Alignment. The SDF antenna may be offset from the runway centerline. For this reason, you must refer to the IAP chart to see at what angle the final approach course will bring you into the runway. Normally this angle is not more than 3°; but because the approach course begins at the SDF antenna, an approach continued beyond the runway threshold will lead your aircraft to an offset position, not to the runway centerline.

4.4.16.5. Identifier. Identification of the SDF is accomplished by the three-letter Morse Code identifier found on the IAP chart.

Chapter 5

WAKE TURBULENCE

5.1. Purpose. This chapter is intended to alert pilots to the hazards of aircraft wake turbulence and to recommend related operational procedures. The information in this chapter was extracted from the FAA's *Advisory Circular (AC) 90-23E, Aircraft Wake Turbulence* and the *Aeronautical Information Manual (AIM).*

5.2. Introduction to Wake Turbulence.

5.2.1. Inflight Hazard. Every aircraft in flight generates wake turbulence. This disturbance is caused by a pair of counter-rotating vortices trailing from the wing tips. The vortices generated by other aircraft (especially aircraft larger than your own) can create serious problems for you. In some cases, the wake of another aircraft can impose rolling moments exceeding the control authority of your aircraft. Additionally, the turbulence generated within the vortices, if encountered at close range, can damage your aircraft and/or cause personal injury to the occupants of your aircraft. It is important for you to imagine the location of the vortex wake generated by other aircraft and adjust your flight path accordingly.

5.2.2. Ground Hazard. Hazardous turbulence isn't only encountered in the air. During ground operations and during takeoff, jet engine blast (thrust stream turbulence) can cause damage and upsets if encountered at close range. Exhaust velocity versus distance studies at various thrust levels have shown a need for light aircraft to maintain an adequate separation behind large turbojet aircraft. Pilots of larger aircraft should be particularly careful to consider the effects of their jet blast on other aircraft, vehicles, and maintenance equipment during ground operations.

5.3. Vortex Generation. Lift is generated by the creation of a pressure differential over the wing surfaces. The lowest pressure occurs over the upper wing surface and the highest pressure occurs under the wing. This pressure differential triggers the rollup of the airflow aft of the wing resulting in swirling air masses trailing downstream of the wingtips. After the rollup is completed, the wake consists of two counter-rotating cylindrical vortices. Most of the energy is within a few feet of the center of each vortex, but pilots should avoid a region within about 100 feet of the vortex core.

5.4. Vortex Strength. The strength of the vortex is governed by the weight, speed, and shape of the wing of the generating aircraft. The vortex characteristics of any given aircraft can also be changed by extension of flaps or other wing configuring devices. However, since the basic factor is weight, the vortex strength increases proportionately with increase in aircraft operating weight. Peak vortex tangential speeds up to almost 300 feet per second have been recorded. The greatest vortex strength occurs when the generating aircraft is HEAVY, CLEAN, AND SLOW.

5.5. Induced Roll and Counter Control.

5.5.1. Induced Roll. In rare instances, a wake encounter could cause in-flight structural damage of catastrophic proportions; however, the most common hazard is associated with induced rolling moments which can exceed the roll control capability of the encountering aircraft. During flight tests, aircraft have been intentionally flown directly up trailing vortex cores of larger aircraft. These tests proved that the capability of an aircraft to counteract the roll imposed by the wake vortex primarily depends on the wing span and counter control responsiveness of the encountering aircraft.

5.5.2. Counter Control. Counter control is usually effective and induced roll is minimal in cases where the wing span and ailerons of the encountering aircraft extend beyond the rotational flow field of the vortex. It is more difficult for aircraft with short wing span (relative to the vortex generating aircraft) to counter the imposed roll induced by vortex flow.

Although pilots of short span aircraft, even of the high performance type, must be especially alert to vortex encounters, the wake of larger aircraft requires the respect of all pilots.

5.6. Vortex Behavior. Trailing vortices have certain behavioral characteristics which can help pilot visualize the wake location and thereby take avoidance precautions.

5.6.1. Vortices are generated from the moment an aircraft leaves the ground because trailing vortices are a by-product of wing lift. Prior to takeoff or landing, pilots should note the rotation or touchdown point of the preceding aircraft.

5.6.2. The vortex circulation is outward, upward, and around the wing tips when viewed from either ahead or behind the aircraft. Tests with large aircraft have shown the vortices remain spaced a bit less than a wing span apart drifting with the wind at altitudes greater than a wing span from the ground. In view of this, if persistent vortex turbulence is encountered, a slight change of altitude and lateral position (preferably upwind) should provide a flight path clear of the turbulence.

5.6.3. Flight tests have shown that vortices from larger (transport category) aircraft sink at a rate of several hundred feet per minute, slowing their descent and diminishing in strength with time and distance behind the generating aircraft. Atmospheric turbulence hastens breakup. Pilots should fly at or above the preceding aircraft's flight path, altering course as necessary to avoid the area behind and below the generating aircraft. As a general rule, vertical separation of 1,000 feet may be considered safe.

5.6.4. When the vortices of a larger aircraft sink close to the ground (within 100 to 200 feet), they tend to move laterally over the ground at a speed of 2 or 3 knots.

5.6.5. A crosswind will decrease the lateral movement of the upwind vortex and increase the movement of the downwind vortex. Thus, a light wind with a cross-runway component of 1 to 5 knots (depending on conditions) could result in the upwind vortex remaining in the touchdown zone for a period of time and hasten the drift of the downwind vortex toward another runway. Similarly, a tailwind condition can move the vortices of the preceding aircraft forward into the touchdown zone. Pilots should be alert to larger aircraft upwind from their approach and takeoff flightpaths.

CAUTION: The light quartering tailwind requires maximum caution.

5.7. Operational Problem Areas. Although most wake encounters are not necessarily hazardous, some can be catastrophic. In 1972, a DC-9 got too close to a DC-10 (two miles back), rolled, caught a wingtip, and cartwheeled coming to rest in an inverted position on the runway. All aboard were killed. Serious and even fatal GA accidents induced by wake vortices are not uncommon.

5.7.1. Wake turbulence encounters can be one or more jolts with varying severity depending upon the direction of the encounter, weight of the generating aircraft, size of the encountering aircraft, distance from the generating aircraft, and point of vortex encounter. The probability of induced roll increases when the encountering aircraft's heading is generally aligned or parallel with the flightpath of the generating aircraft.

CAUTION: Avoid the area below and behind the preceding aircraft especially at low altitude where even a momentary wake encountrer could be hazardous.

5.7.2. Pilots should be particularly alert in calm wind conditions and maneuvering situations in the vicinity of the airport where the vortices could:

- Remain In the touchdown area.
- Drift from aircraft operating on a nearby runway.
- Sink into takeoff or landing path from crossing runway.
- Sink into the traffic patterns from other airport operations.
- Sink into the flight path of aircraft operating VFR.

5.7.3. Pilots of all aircraft should visualize the location of the vortex trail behind larger aircraft and use proper vortex avoidance procedures to achieve safe operation. It is equally important that pilots of larger aircraft plan or adjust their flightpaths, whenever possible, to minimize vortex exposure to other aircraft.

5.8. Vortex Avoidance Techniques. Under certain conditions, airport traffic controllers apply procedures for separating aircraft operating under IFR. The controllers will also provide to VFR aircraft, with whom they are in communication and which in the tower's opinion may be adversely affected by wake turbulence from a larger aircraft, the position, altitude and direction of flight of larger aircraft followed by the phrase “CAUTION--WAKE TURBULENCE.” Whether or not a warning has been given, pilots are expected to adjust their operations and flight path(s) as necessary to avoid serious wake encounters. The following vortex avoidance procedures are recommended for the situation shown:

5.8.1. When landing behind a larger aircraft on the same runway: stay at or above the larger aircraft's final approach flight path; note the touchdown point; land beyond it.

5.8.2. When landing behind and offset from a larger aircraft which is landing on a parallel runway and the parallel runway is closer than 2,500 feet: consider possible vortex drift onto your runway; stay at or above the larger aircraft's final approach flight path; note its touchdown point.
5.8.3. When landing behind a larger aircraft on a crossing runway: cross above the larger aircraft's flightpath.
5.8.4. When landing behind a departing larger aircraft on the same runway: note larger aircraft's rotation point; land well prior to rotation point.
5.8.5. When landing behind a departing larger aircraft on a crossing runway: note larger aircraft's rotation point; if past the intersection--continue the approach--land prior to the intersection; if prior to the intersection--abandon the approach unless a landing is assured well before reaching the intersection--avoid flight below the larger aircraft's flightpath.
5.8.6. When departing behind a larger aircraft: note larger aircraft's rotation point; rotate prior to larger aircraft's rotation point; continue climb above the larger aircraft's climb path until turning clear of the larger aircraft's wake. Avoid subsequent headings which will cross below and behind a larger aircraft. Be alert for any critical takeoff situation which could lead to a vortex encounter.
5.8.7. Intersection takeoffs on same runway: be alert for adjacent large aircraft operations particularly upwind of your runway; avoid headings which will cross below a larger aircraft's path.
5.8.8. Departing or landing after a larger aircraft executing a low approach, missed approach or touch-and-go landing. Because vortices settle and move laterally near the ground, the vortex hazard may exist along the runway and in your flight path after a larger aircraft has executed a low approach, missed approach or a touch-and-go landing, particular in light quartering wind conditions. You should ensure that an interval of at least 2 minutes has elapsed before your takeoff or landing.
5.8.9. Enroute VFR--(1,000 foot altitude plus 500 feet). Avoid flight below and behind a larger aircraft's path. If a larger aircraft is observed above on the same track (meeting or overtaking), adjust your position laterally, preferably upwind.

5.9. Helicopters. In a slow hover taxi or stationary hover near the surface, helicopter main rotor(s) generate downwash producing high velocity outwash vortices to a distance approximately three times the diameter of the rotor. When rotor downwash hits the surface, the resulting outwash vortices have behavioral characteristics similar to wing tip vortices produced by fixed wing aircraft. However, the vortex circulation is outward, upward, around, and away from the main rotor(s) in all directions. Pilots of small aircraft should avoid operating within three rotor diameters of any helicopter in a slow hover taxi or stationary hover. In forward flight, departing or landing helicopters produce a pair of strong, high speed trailing vortices similar to wing tip vortices of larger fixed wing aircraft. Pilots of small aircraft should use caution when operating behind or crossing behind landing and departing helicopters.

5.10. Jet Engine Exhaust. During ground operations, jet engine blast (thrust stream turbulence) can cause damage and upsets if encountered at close range. Exhaust velocity versus distance studies at various thrust levels have shown a need for light aircraft to maintain an adequate separation during ground operations.
5.10.1. Engine exhaust velocities, generated by larger jet aircraft during ground operations and initial takeoff roll, dictate the desirability of lighter aircraft awaiting takeoff to hold well back of the runway edge at the taxiway hold line. Also, it is desirable to align the aircraft to face any possible jet engine blast effects. Additionally, in the course of running up engines and taxiing on the ground, pilots of larger aircraft should consider the effects of their jet blasts on other aircraft, vehicles, and maintenance and servicing equipment.
5.10.2. The FAA has established standards for the location of runway hold lines. For example, runway intersection hold short lines are established 250 feet from the runway centerline for precision approach runways served by approach category C and D aircraft. For runways served by aircraft with wingspans over 171 feet, such as the B-747, taxiway hold lines are 280 feet from the centerline of precision approach runways. These hold line distances increase slightly with an increase in field elevation.

5.11. Pilot Responsibility. Government and industry groups are making concerted efforts to minimize or eliminate the hazards of trailing vortices; however, the flight discipline necessary to ensure vortex avoidance during VFR operations must be exercised by the pilot. Vortex visualization and avoidance procedures should be exercised by the pilot using the same degree of concern as in collision avoidance.
5.11.1. Pilots are reminded that in operations conducted behind all aircraft, acceptance of instructions from ATC in the following situations is an acknowledgement that the pilot will ensure safe takeoff and landing intervals and accepts the responsibility for providing wake turbulence separation:

- Traffic information,
- Instructions to follow an aircraft, and/or
- The acceptance of a visual approach clearance.

5.11.2. For operations conducted behind heavy aircraft, ATC will specify the word "heavy" when this information is known. Pilots of heavy aircraft should always use the word "heavy" in radio communications.
5.11.3. For VFR departures behind heavy aircraft, air traffic controllers are required to use at least a 2 minute separation interval unless a pilot has initiated a request to deviate from the 2 minute interval and has indicated acceptance of responsibility for maneuvering his/her aircraft so as to avoid the wake turbulence hazard.

5.12. ATC Wake Turbulence Separation.
5.12.1. Required Separation Behind Heavy Jets. Because of the possible effects of wake turbulence, controllers are required to apply no less than specified minimum separation for aircraft operating behind a heavy jet and, in certain instances, behind large non-heavy aircraft.
5.12.1.1. Separation is applied to aircraft operating directly behind a heavy jet at the same altitude or less than 1,000 feet below:

- Heavy jet behind heavy jet--4 miles.
- Small/large aircraft behind heavy jet--5 miles

5.12.1.2. Also, separation, measured at the time the preceding aircraft is over the landing threshold, is provided to small aircraft:

- Small aircraft landing behind heavy jet--6 miles
- Small aircraft landing behind large aircraft--4 miles

5.12.1.3. Additionally, departing aircraft will be separated by either 2 minutes or the appropriate 4 or 5 mile radar separation when the takeoff behind a heavy jet will be:

- from the same threshold
- on a crossing runway and projected flight paths will cross
- from the threshold of a parallel runway when staggered ahead of that of the adjacent runway by less than 500 feet and when the runways are separated by less than 2,500 feet.

NOTE: Pilots, after considering possible wake turbulence effects, may specifically request waiver of the 2 minute interval by stating, "request waiver of 2 minute interval" or a similar statement. Controllers may acknowledge this statement as pilot acceptance of responsibility for wake turbulence separation and, if traffic permits, issue takeoff clearance.

5.12.2. Required Separation Behind Larger Aircraft. A 3 minute interval will be provided when a small aircraft will takeoff:

- From an intersection on the same runway (same or opposite direction) behind a departing large aircraft.
- In the opposite direction on the same runway behind a large aircraft takeoff or low/missed approach.

NOTE: This 3 minute interval may be waived upon specific pilot request.

5.12.3. A 3 minute interval will be provided for all aircraft taking off when the operations are as described in 5.12.2 above, the preceding aircraft is a heavy jet, and the operations are on either the same runway or parallel runways separated by less than 2,500 feet. Controllers may not reduce or waive this interval.
5.12.4. Pilots may request additional separation, that is, 2 minutes instead of 4 or 5 miles for wake turbulence avoidance. This request should be made as soon as practical on ground control and at least before taxiing onto the runway.
5.12.5. Controllers may anticipate separation and need not withhold a takeoff clearance for an aircraft departing behind a large/heavy aircraft if there is reasonable assurance the required separation will exist when the departing aircraft starts takeoff roll.

Chapter 6

THE 60-TO-1 RULE

6.1. What is the 60-to-1 Rule and Why Should You Use It? It is a technique for establishing predictable pitch changes and lead points for intercepting courses or arcs. Listed below are three good reasons for using this rule:

- It allows the pilot to compute the pitch changes necessary when establishing an attitude during the control and performance concept (establish pitch, trim, cross-check, and adjust) of attitude instrument flying.
- It reduces the pilot's workload and increases efficiency by requiring fewer changes and less guesswork.

- It is an alternative to the TLAR (That Looks About Right) method of flying. This alternative is something you as an instructor can teach—as opposed to trying to teach experience. After gaining experience using the 60-to-1 rule, it will improve your TLAR accuracy.

6.2. When Do You Use the 60-to-1 Rule? Here are examples of the types of pilot problems that can be readily solved by applying the 60-to-1 rule:

- You're in level flight and flying 400 KTAS airpeed and you want to establish a rate of climb or descent of 1,000 feet per minute (feet/MIN). What pitch change will give you the desired rate of climb or descent?
- You're at 80 DME, at Flight Level 310 inbound to XYZ VORTAC, and you want to cross the VORTAC at 5,000 feet. When should you start your descent and what pitch change should you make?
- You're climbing at 3,000 feet/MIN at 250 KIAS. What pitch change will be necessary to level your aircraft at FL 350?

6.3 How to Work With the 60-to-1 Rule. The 60-to-1 rule gives us a mathematical equation to help you figure out all these questions, but its almost impossible to run these calculations and fly at the same time. You need to use the formulas before you fly. Find out what your turn radius is at cruise airspeed up high and at approach airspeed down lower, find out what a 1 degree pitch change will do to your VVI, and remember those numbers. Take your approaches out prior to flight and write in your lead radials and VVIs right on the IAP. After a while, you will find that certain values keep coming up. Then when you are flying, you can use these numbers to enhance your TLAR method and make your flying more precise.

6.4. Mathematical Data Supporting the 60-to-1 Rule. Let's relate this to a VORTAC station. We know that the formula for the circumference of a circle = $2\pi r$. Therefore, the circumference of a 60 NM circle around our VORTAC is:

C = (2) (3.14) (60)
C = 376.99 NM for a 60 NM radius circle

6.4.1. Because there are 360° in a circle, we can determine the length of a 1° arc:

$$\frac{376.99}{360} = 1.0472 \text{ NM or}$$

approximately 1 NM per degree at 60 NM

6.4.2. Because 1 NM = 6,076 feet or approximately 6,000 feet, we can therefore say: 1° = 6,000 feet at 60 NM. This relationship is true not only in the horizontal plane, but also in the vertical plane. If we were to make a 1° dive, then we would have descended 6,000 feet (1 NM) after traveling 60 NM. Through the magic of algebra, we can break this down to 100 feet per NM for a 1° dive or pitch change.

6.5. VVI Versus Pitch change. We now know how to calculate the altitude gained or lost for each degree of pitch change over a given distance. Throw in a time factor using True Airspeed (TAS) expressed in NM per MIN and we can relate this pitch change to a change in VVI.

6.5.1. First, let's convert speed to NM/MIN, since the 60-to-1 rule is based on True Airspeed (TAS) expressed in NM/MIN. NM/MIN can be obtained easily from either TAS or the Indicated Mach Number (IMN) as follows:

- Directly from TAS:

$$\frac{\text{TAS}}{60} = \text{NM/MIN}$$

Example: $\frac{420 \text{ TAS}}{60} = 7 \text{ NM/MIN}$

- From IMN:

IMN X 10 = NM/MIN

Example: .7 Mach X 10 = 7 NM/MIN

- If you don't have a TAS indicator or an IMN, TAS can be computed from Indicated Airspeed (IAS). TAS increases over IAS at the rate of 2 percent per 1,000 feet altitude increase. So, use the equation:

TAS = IAS + (2% per 1,000 feet) (IAS)

Example: FL 200; 270 KIAS

TAS = 270 + (2%. X 20) (270) = 270 + (.40) X (270) = 378 KTAS

- Another easy but less accurate formula (best between 10,000 feet and FL 350) is:

$$TAS = \frac{FL}{2} + IAS$$

Example: FL 200; 270 KIAS

$$TAS = \frac{200}{2} + 270 = 100 + 270 = 370 \text{ KTAS}$$

NOTE: These basic expressions of TAS and NM/MIN will be used often in future discussions.

6.5.2. If one degree equals 100 feet per NM, then our VVI can be calculated by:

VVI = NM/MIN X 100 feet

Example #1: For .6 Mach and a 1° pitch change:

IMN X 10 = NM/MIN

0.6 X 10 = 6 NM/MIN

VVI for 1° pitch change = NM/MIN X 100 = 6 X 100 = 600 feet/MIN

Example #2: For 420 KTAS and a 2° pitch change:

$$\frac{TAS}{60} = NM/MIN \qquad \frac{420 \text{ KTAS}}{60} = 7 \text{ NM/MIN}$$

VVI for 1° pitch change = NM/MIN X 100

VVI for 2° pitch change = 2 X NM/MIN X 100 = 2 X 7 X 100 = 1,400 feet/MIN

6.6. Descent Gradients for Approaches or Enroute Descents. Now let's look at a real world application to relate it all together. You are flying along fat, dumb and happy when ATC says directs you to cross the ABC VORTAC at 12,000 feet. A quick glance inside shows you are 25 NM from the ABC VORTAC. You are at FL 270 and you are cruising at 0.75 Mach. What descent gradient is required and what VVI should you expect?

6.6.1. First, you need to know what your descent gradient has to be. You can find the descent gradient by applying the 60-to-1 relationship of 100 feet per NM. To lose 15,000 feet in 25 NM, you'll need a descent gradient of 600 feet/NM or about a 6° pitch change. Here's the math:

$$\text{Descent gradient} = \frac{\text{100s of feet}}{\text{Distance in NM}} = \left(\frac{150}{25}\right) = 6$$

6.6.2. Now that you know what descent gradient is required, you can compute what your VVI should be if you make a pitch change of 6° while flying at 0.75 M. In this case, your VVI will be 4,500 FEET/MIN to begin with. If you hold 0.75 M all the way down, the VVI will work.

IMN X 10 = NM/MIN

0.75 X 10 = 7.5 NM/MIN

VVI = Angle (NM/MIN X 100) = 6 (7.5 X 100) = 4500 feet/MIN

6.6.3. If you maintain an IAS throughout the descent, as many of us do, then your TAS will decrease as you get lower meaning the VVI required to maintain the 6° descent gradient will slowly decrease as you descend. If you hold 4,500 FEET/MIN all the way down to 12,000 feet, you will get down early. The most important part of the equation (which remains constant no matter what speed you are flying) is the descent gradient. You must descend at 600 feet/NM (or about 6°) in order to make the altitude restriction at the ABC VORTAC.

6.7. Climb Gradients. As you might suspect, computing a climb gradient is really no different than the en route descent calculations, but let's run an example to see how it's done. Let's say you are getting ready to fly a Standard Instrument Departure (SID). You look at the plate and see that you will need a climb gradient of 350 FEET/NM to 10,000 feet. So, we need to climb out at a 3.5° angle. Our best climb airspeed is 200 KIAS. The airport is 3,000 Feet MSL.

6.7.1. First, we need to calculate our TAS. In this case, 200 KIAS at 3,000 feet MSL works out to 212 KTAS and 200 KIAS at 10,000 feet MSL is 240 KTAS. Dividing each of these by 60 will give you your speed in NM/MIN at 3,000 and 10,000 feet respectively.

<u>At 3,000 feet MSL:</u>

TAS = IAS + (2% per 1,000 feet) = 200 + (3 X .02 X 200) = 200 + 12 = 212 KTAS

$$\text{NM/MIN} = \frac{\text{TAS}}{60} = \frac{212}{60} = 3.5\ \text{NM/MIN.}$$

<u>At 10,000 feet MSL:</u>

TAS = 200 + (10 X .02 X 200) = 200 + 40 = 240 KIAS.

$$\text{NM/MIN} = \frac{\text{TAS}}{60} = \frac{240}{60} = 4\ \text{NM/MIN.}$$

6.7.2. Next, calculate your VVI. Immediately after takeoff, your VVI will be 1,225 FEET/MIN. As you climb (and your TAS increases), your VVI will slowly increase to approximately 1,400 FEET/MIN. There are a couple of techniques to deal with the change in TAS. One technique is to just use the higher VVI (1,400 FEET/MIN) throughout the climb. Another way to figure a target VVI is to use an average true airspeed (For example, using your TAS at 6,500 feet MSL). Better yet, use groundspeed instead of TAS—using groundspeed accounts for wind.

<u>At 10,000 feet MSL:</u>

VVI = Angle (NM/MIN X 100) = 3.5 (3.5 X 100) = 1225 feet/MIN

<u>At 10,000 feet MSL:</u>

VVI = Angle (NM/MIN X 100) = 3.5 (4.0 X 100) = 1400 feet/MIN

6.8. Calculating a Visual Descent Point (VDP). The first step to computing a VDP is to divide the Height Above Touchdown (HAT) from your approach procedure by your desired descent gradient. Most pilots use a 3° (300 feet/NM) glidepath for landing. Here's the formula to use:

$$\frac{\text{HAT}}{\text{Gradient (normally 300)}} = \text{VDP in NM from end of runway}$$

6.8.1. Now that you know how far the VDP is from the end of the runway, you may add this distance to the DME at the end of the runway to get a DME for your VDP. Armed with this information, it is easy to compute the distance from the FAF to the VDP. This distance is important in computing the climb gradient necessary for final approach.
6.8.2. Using the FAF altitude, the MDA, and the distance from the FAF to the VDP, you can compute a descent gradient from the FAF to the VDP along with a target VVI to ensure you are meeting the desired descent gradient.

Example: Use the following information to determine the descent gradient from the FAF to the VDP:
HAT = 420 feet, MDA = 840 feet MSL, DME at the end of the runway = 0.5 DME, FAF = 6 DME, FAF altitude = 2,500 feet MSL, desired landing gradient = 300 feet/NM, Approach airspeed = 150 KTAS, no wind.

$$\text{VDP} = \frac{\text{HAT}}{\text{Gradient}} = \frac{420}{300} = 1.4 \text{ NM}$$

VDP DME = DME at end of runway + VDP distance = 0.5 DME + 1.4 DME = 1.9 DME

Descent Distance = FAF DME - VDP DME = 6.0 DME - 1.9 DME = 4.1 DME

Altitude to lose = FAF altitude - MDA = 2500 - 840 = 1,660 feet

$$\text{Descent Gradient} = \frac{\text{altitude to lose}}{\text{distance}} = \frac{1660}{4.1} = 405 \text{ feet/NM } (4° \text{ descent gradient})$$

VVI = Angle (NM/MIN X 100) = 4 (2.5 X 100) = 1,000 feet/MIN

6.8.3. With this information you can depart the FAF maintaining a 4° descent gradient (400 feet/NM). Your target VVI is 1,000 FEET/MIN. Each mile you should lose 400 feet. At 5 DME, you should be at 2,100 feet, at 4 DME, 1,700 feet, etc . . . Continue this descent gradient until reaching VDP at 840 feet MSL. Hopefully, at the VDP, you'll have the runway in sight. Adjust your descent to a 300 feet/NM gradient and pick up your normal aim point.

6.9. Precision Glide Path. The glide path published for an approach will be the same for every aircraft. Therefore, a pitch change equal to the published glide path can be made on the attitude indicator when intercepting the glide path. Aircraft speed has no effect upon the amount of pitch change required when intercepting the glide path. Speed only affects the time required to fly the final approach segment and your rate of descent (VVI).
6.9.1. Prior to intercepting the glide path, compute the target VVI for your planned approach airspeed (corrected for wind). (There's also a chart in the back of the approach plate that does this for you.) When you intercept the glide path, crosscheck your actual VVI; it should be close to your target VVI. Compute the VVI with the same formula used before:

VVI = Angle (NM/MIN X 100)

Example #1: An F-15 on a 3° glide path at .3 Mach

NM/MN = IMN X 10 = .3 X 10 = 3 NM/MIN

VVI for 3° glide path = 3 (NM/MIN X 100) = 3 (3 X 100) = 900 FEET/MIN

Example #2: T-37 on a 2.5° glide path at 120 KTAS

$$\text{NM/MIN} = \frac{\text{TAS}}{60} = \frac{120}{60} = 2 \text{ NM/MIN}$$

VVI = Angle (NM/MIN X 100) = 2.5 (2 NM/MIN X 100) = 500 FEET/MIN

6.9.2. Another way to approximate the VVI for a 3° glide path can be computed using the formula:

$$\text{VVI for } 3° = \frac{\text{TAS X 10}}{2}$$

$$\text{VVI for } 2.5° = \frac{\text{TAS X 10}}{2} - 100$$

NOTE: The formula for a 3° glide path VVI comes from previous formulas.

VVI = NM/MIN X 100 X degrees. Remember, NM/MN = TAS/60, so:

$$\text{VVI} = \frac{\text{TAS}}{60} \text{ X 100 X degrees}$$

$$\text{So, for a } 3° \text{ glide pathVVI} = \frac{\text{TAS X 100 X 3}}{60} = \frac{\text{TAS X 30 X 10}}{60} = \frac{\text{TAS X 10}}{2}$$

But TAS is used for “air mass” determinations. For relationships with the surface, substitute Ground Speed (GS), which is TAS corrected for wind, for TAS. Therefore, the formula becomes:

$$\text{VVI for } 3° = \frac{\text{GS X 10}}{2}$$

6.10. Determining Turn Radius (TR). TR is not really a 60-to-1 relationship, but a great deal of the calculations are based on your turn radius. Therefore, it is important to determine your TR at various altitudes and airspeeds and remember those numbers so that you can use them later.

6.10.1. An aircraft’s turn radius is dependent on TAS and angle of bank. The higher the TAS, the larger the TR. As bank angle is increased, the TR decreases. In order to develop a technique for determining your TR, you must keep one of the variables (TAS or bank) constant. Since most procedures are based on a 30° bank, you should first expect to use a constant 30° bank for your turns.

6.10.2. The following two relationships will provide the distance required to turn an aircraft 90° using 30° of bank. This distance will be your TR.

TR = NM/MIN - 2 or (IMN X 10) - 2

TR = $(\text{NM/MIN})^2$ / 10 or IMN^2 X 10

6.10.3. The first relationship above is easier to use, but doesn’t give as accurate a TR as the second Mach squared formula. The actual turn performance curve (dashed line) is derived from Volume 1’s General Turning Performance Chart (formerly AFM 51-37). You can see that the IMN^2 method is closer to the actual turning performance line than the Mach - 2 method. At the largest spread, the Mach - 2 line only varies by 0.5 NM. This should be close enough for most instrument maneuvers, especially since it is on the conservative side. That is, it will provide more TR than required which you can adjust by decreasing your bank. It’s normally not advisable to increase your bank past 30° in instrument meteorological conditions (IMC) because the possibility of becoming spatially disoriented increases as your bank increases. With this in mind, it will be better to have allowed for too much TR than not enough. The Mach - 2 method will usually provide enough TR at the lower airspeeds. Once you get past Mach .8 (480 KTAS), the difference becomes quite large, but few aircraft accomplish instrument procedures at this speed. Nevertheless, if you want to be more accurate, use the IMN^2 method.

Example: TAS = 300, IMN = 0.5, NM/MIN = 5

$$\text{TR} = 5 - 2 \text{ or } (0.5 \text{ X } 10) - 2 = 3 \text{ or } = \frac{(5)2}{10} \text{ or } (0.5)^2 \text{ X } 10 = 2.5$$

Use the method that works the best and easiest for you. As long as you use a technique to determine your lead point, your instrument flying will be more precise.

6.10.4. The techniques just described work well for 30° of bank, but what if you need to use a standard rate turn (SRT)? The following formulas will provide you the TR for SRTs and ½ SRTs.

SRT = 0.5% of KTAS (or GS)

½ SRT = 1% of KTAS (or GS)

Example: TAS = 400

SRT = 0.5% (400) = .005(400) or 0.5(.01)(400) = 2 NM

½ SRT = 1% (400) = .01(400) = 4 NM

By using groundspeed you can obtain a "winded" lead point.

6.10.5. While we are discussing standard rate turns, here are a couple of relationships that will give you the bank angle to approximate the SRT.

$$\text{Bank Angle for SRT} = \frac{TAS}{10} + 7$$

$$\text{Bank Angle for ½ SRT} = \frac{TAS}{20} + 7$$

Example: TAS = 180

$$\text{Bank Angle for SRT} = \frac{TAS}{10} + 7 = \frac{180}{10} + 7 = 18 + 7 = 25°$$

$$\text{Bank Anglefor ½ SRT} = \frac{TAS}{20} + 7 = \frac{180}{20} + 7 = 9 + 7 = 16°$$

6.10.6. What if your turn is something other than 90°? A simple rule of thumb is to turn before your computed lead point for turns greater than 90°, and turn after your lead point for turns less than 90°. How much before or after depends on how much more or less than 90° of turn you have. The following relationships will help you determine a more accurate lead point:

Degrees to turn	**Part of 90° lead**
180°	2
150°	1 5/6
135°	1 2/3
120°	1 1/2
90°	1
60°	1/2
45°	1/3
30°	1/6

6.10.7. It's not as confusing as it looks. If you have 180° of turn, you must offset yourself 2 TR (one diameter) to turn and intercept your desired course. For 60° of turn (intercept), you only need one-half of your computed lead point. The following gives you sample computations for 3 NM TR.

Example: Turn radius = 3 NM

For 180° turn	=	2 X 3	=	6 NM lead
150°	=	1 5/6 X 3	=	5 1/2 NM lead
135°	=	1 2/3 X 3	=	5 NM lead
120°	=	1 1/2 X 3	=	4 1/2 NM lead
90°	=	1 X 3	=	3 NM lead
60°	=	1/2 X 3	=	1 1/2 NM lead
45°	=	1/3 X 3	=	1 NM lead
30°	=	1/6 X 3	=	1/2 NM lead

6.10.8. If these above fractions are getting too mind boggling, you only really have to remember the following four relationships to figure sufficient lead points for virtually all your instrument flying:

Degrees to turn	Part of 90° lead
180°	2
120°	1 ½
90°	1
60°	½

6.10.9. As long as you know the above lead points, you will be successful in most, if not all, course intercepts. When making intercepts requiring less than 60° of turn, your lead point is so small it is not worth calculating.

6.11. Arcs. Now that we know how to determine our TR, let's see how we can use it in combination with our 60-to-1 rule to apply it to our instrument maneuvers in the horizontal.

6.11.1. Lead Radials. Remember the VORTAC with the 60 NM circle around it? We said that at 60 NM (or 60 DME), 1° = 1 NM. Therefore, if your TR is 1 NM and you want to intercept a radial at a 90° angle, you should turn 1° (or 1 radial) prior to the desired radial to roll out on it. If your turn radius is 4 NM, you need to turn 4° (or 4 radials) prior. This works well at 60 DME, but what do you do at other DMEs? All you need is a relationship to give you this information for any distance from the NAVAID. If you are at 30 DME, it will take twice as many radials for the 1 NM lead point as at 60 DME. This can be put into the following relationship:

$$\text{Radials per NM} = \frac{60}{\text{Arc (DME)}}$$

Lead radials = TR X Radials/NM

Example #1: At 20 DME how many radials are there per nautical mile?

$$\text{Radials per NM} = \frac{60}{\text{Arc (DME)}} = \frac{60}{20} = 3 \text{ Radials/NM}$$

Example #2: If you are on the 10 DME arc and require a 2 NM lead, how many radials of lead are required?

$$\text{Radials per NM} = \frac{60 \text{ X } 2 \text{ NM lead}}{10 \text{ DME}} = 12 \text{ radials}$$

6.11.2. Lead DME. If you are on a radial and trying to intercept an Arc, then the math is pretty easy. Simply add or subtract your TR from the DME of the arc that you are intercepting.

Example: TAS = 300 knots; Inbound to intercept the 20 DME Arc;

TAS = .5 Mach or 5 NM/MIN

Lead point in DME = TR ± desired arc

TR = NM/MIN - 2 or $(NM/MIN)^2$ / 10 = 3 NM or 2.5 NM

Lead point in DME = 3 (or 2.5) + 20 DME = 23 or 22.5 DME

In order to intercept the 20 DME arc you would begin a 30° bank turn at 23 DME. If you wanted to be more accurate you would begin the turn at 22.5 DME. Both would roll you out very close to the 20 DME arc.

6.11.3. Maintaining The Arc. Now let's look at how you can stay on the arc. You could maintain the arc by either flying a series of straight legs or by maintaining a constant bank. The bank required to maintain the 20 DME arc can be found using the following relationship:

$$\text{Required Bank Angle} = \tfrac{1}{2}\frac{60\ \text{TR}}{\text{Arc}}\ \text{(the lead for an arc-to-radial intercept) or } \frac{30\ \text{TR}}{\text{Arc}}$$

Example: TAS = 300 knots, IMN = 0.5, NM/MIN = 5;

TR = NM/MIN - 2 or $(NM/MIN)^2$ / 10 = 3 NM or 2.5 NM

$$\text{Required bank angle} = \frac{30}{20} \times 3\ (\text{or } 2.5) = 4.5° \text{ or } 3.75° \approx 4° \text{ of bank to maintain the arc}$$

NOTE: Maintaining a constant bank on an arc, may be conducive to spatial disorientation (the leans). However, a constant bank may be the only way to safely maintain a tight arc, a 6 DME arc, for example.

6.11.4. Turning Off the Arc. Now that you are established on the arc how are you going to get off the 20 DME arc and onto the 120° radial? If you already know the amount of bank required to maintain the arc, you have got half the answer for determining the lead point (for getting off the arc and onto the radial). We say literally half the answer, because all you have to do is double (X 2) the bank to get your lead. In the above example where 4.5° of bank is required to maintain the arc, 9° radials of lead point would be required to intercept the 120° radial. Another way, is to use the relationship:

Lead Point (in degrees) = 60/DME X TR (in NM)

Example: TAS = 300 KTS IMN = 0.5 NM/ MIN = 5

TR = NM/MIN - 2 = 3 NM

$$\text{Lead Point} = \frac{60}{20} \times 3 = 9°$$

As you can see, 9° is the same as the 9° you got by doubling the bank required on the arc. You can also take half of the computed lead point in degrees to determine the bank angle required to maintain the arc. This result is still close to 4°. (It is as close as you could probably fly the bank.)

6.12. Procedure Turns (PTs). Another place you can use your aircraft's TR is when you are flying procedure turns. There are several different methods for flying these turns.

6.12.1. The first method we will discuss is the 45°/180° maneuver. Procedure turn approaches will have a remain within a distance of either 10 or 15 NM. How much of the remain within distance will you use when doing the 45°/180° maneuver? The following relationship will provide you the answer:

45°/180° Maneuver Distance = (3 X TR) + 2

Example: TR = 1 NM (180 KTAS)

Maneuver Distance = (3 X 1) + 2 = 5 NM

5 NM of your remain within distance will be used in executing the 45°/180° maneuver. Therefore, if your remain within distance is 10 NM, you must begin your 45/180 no later than 5 NM from the procedure turn fix (no wind).

6.12.2. If you are going to fly the 80°/260° maneuver, use the following relationship to compute this distance:

80°/260° Maneuver Distance = 3 X TR.

Example: TR = 1 NM (180 KTAS)

80°/260° Maneuver Distance = 3 X 1 = 3 NM

3 NM of your remain within distance will be used by the 80°/260° maneuver. Therefore, if your remain within distance is 10 NM, you can go outbound no farther than 7 NM from the procedure turn fix before starting your 80/260 maneuver (no wind).

6.13. Teardrops.

6.13.1. Determining Outbound Distance. Say you are on a teardrop approach. How far outbound should you go so you can turn inbound and roll out on the course inbound? The following relationship gives you the answer, using 30° bank for the inbound turn:

$$\frac{\text{Turn Diameter X 60}}{\text{Degrees Between Radials}} = \text{Distance Outbound}$$

Turn diameter is 2 TR. So, we can simplify the equation to:

$$\frac{\text{120 TR}}{\text{Degrees Between Radials}} = \text{Distance Outbound}$$

Example #1: TR = 2 NM (240 KTAS); Outbound Radial = 045; Inbound Radial = 015;

Degrees Between Radials = 45 - 15 = 30

$$\text{Distance Outbound} = \frac{120 \text{ X } 2}{30} = \frac{240}{30} = 8 \text{ NM}$$

By going outbound on the 045 radial for 8 NM and turning left using 30° of bank, you will go out another 2 NM in the turn using 10 NM of airspace. Make sure this is less than your “remain within” distance. If you slowed down to 180 KTAS you would not need to use as much airspace. This is shown in the following example.

Example #2: TR = 1 NM (180 KTAS)

$$\text{Distance Outbound} = \frac{120}{30} = 4 \text{ NM}$$

When you used a slower airspeed your outbound distance requirement is 4 NM + 1 NM for the turn. Slowing down to 180 KTAS gained you 5 miles of extra airspace to work with.

6.13.2. Determining Bank Angle required. If the teardrop approach has a hard turn point, how can you determine the bank angle required to make a smooth intercept? The following formula will help:

$$\frac{\text{60 TR}}{\text{Distance Between Radials}} = \text{Degrees of Bank Required}$$

$$\text{Distance Between Radials} = \frac{\text{Radials X DME}}{60}$$

The aircraft is going outbound on the 060° radial and wants to roll out inbound on the 100° radial. If the aircraft must start the turn at 20 DME, what constant bank angle will result in you rolling out on the 100° radial inbound? The following example should answer the question.

Example: TAS = 300 KTS IMN = 0.5 NM/MIN = 5

TR = NM/MIN - 2 or $(\text{NM/MIN})^2$ / 10 = 3 NM or 2.5 NM

$$\text{Distance Between Radials} = \frac{\text{Radials X DME}}{60} = \frac{40 \text{ X } 20}{60} = \frac{800}{60} = 13.3 = 13 \text{ NM}$$

$$\text{Bank Required} = \frac{3 \text{ (or 2.5) X } 60}{13} = 14° \text{ or } 12° \text{ of bank}$$

Depending upon which method you use for determining TR, you get either 14° or 12° of bank to roll out on the 100° radial inbound. This will make flying the procedure easy, using a constant bank all the way around the turn.

6.14. Teardrop Offset. What if you want to use all of your available airspace to go outbound and have just enough room to turn inbound on course (such as in a teardrop entry for holding or PTs)? How do you calculate the proper offset to achieve the proper spacing? The new relationship will be:

$$\frac{\text{Turn Diameter X 60}}{\text{Leg Length}} = \text{Degrees Offset}$$

Since Turn Diameter (TD) = 2TR, we can use:

$$\frac{120 \text{ TR}}{\text{Leg Length}} = \text{Offset}$$

Example: TR = 1 NM (180 KTAS); 5 NM legs (holding pattern)

$$\text{Offset} = \frac{120}{5} = 24°$$

Using 24° offset teardrop for the outbound leg, will allow you to rollout on course inbound using a 30° bank turn. For a PT, your leg length will be the "remain within" distance minus your TR. This will allow no room for error or winds. You should allow at least 2 NM for slow turn rates, wind, etc. This same relationship can be used for any teardrop approach procedure where 30° of bank will provide the bank around the turn.

6.15. Important 60-to-1 Rule Formulas and Relationships. Here are some items for review:

6.15.1. The 60-to-1 Rule.

1° = 1 NM at 60 NM 1° = 100 feet at 1 NM

6.15.2. Climbs and Descents.

$$\text{Required Gradient (feet/NM)} = \frac{\text{altitude to lose (or gain)}}{\text{distance to travel}}$$

$$\text{Pitch Change} = \frac{\text{100s of FT}}{\text{Distance}} \quad \text{(1° pitch change = 100 feet/NM)}$$

6.15.3. VVI.

VVI = Gradient (or pitch X 100) X TAS in NM/MIN

$$\text{VVI for 3° glideslope} = \frac{\text{GS X 10}}{2}$$

$$\text{VVI for 2.5° glideslope} = \frac{\text{GS X 10}}{2} - 100$$

NOTE: To compensate for wind, simply substitute Ground Speed for TAS. For practical applications, each 60 KTS of wind will change pitch 1°.

6.15.4. Determining TAS and NM/MIN.

KTAS = IMN X 600 or KTAS = KIAS + (2% per 1000 feet) X KIAS

$$\text{KTAS} \approx \text{KIAS} + \frac{\text{FL}}{2}$$

$$\text{TAS (NM/MIN)} = \frac{\text{KTAS}}{60}$$

TAS (NM/MIN) = IMN X 10

6.15.5. Turn Radius (TR).

6.15.5.1. TR using 30° of bank.

NM/MIN - 2 or (IMN X 10) - 2

$(\text{NM/MIN})^2 / 10$ or IMN^2 X 10

6.15.5.2. TR using Standard Rate Turns and ½ Standard Rate Turns.

SRT = 0.5% of TAS (or GS)

½ SRT = 1% of TAS (or GS)

6.15.5.3. Bank for rate turns.

$$\text{Bank for SRT} = \frac{\text{KTAS}}{10} + 7$$

$$\text{Bank for ½ SRT} = \frac{\text{KTAS}}{20} + 7$$

6.15.5.4. For turns less or more than 90° use the following:

Degrees to turn	Fraction of 90° turn
*180°	2
150°	1 5/6
135°	1 2/3
*120°	1 1/2
*90°	1
*60°	1/2
45°	1/3
30°	1/6

*Try to remember these; they cover most situations.

6.15.6. Determining Lead Point for Radial to Arc or 90° Intercept of Arc.

Lead Point in DME = TR ± desired Arc DME

6.15.7. Determining Lead Point for Arc to Radial Intercept or 90° Intercept of Radial.

$$\text{Lead Point (in degrees)} = \frac{60\ (\text{TR})}{\text{Arc}}$$

6.15.8. Determining Bank Angle Required to Maintain an Arc.

$$\text{Required Bank Angle} = \frac{30\ (\text{TR})}{\text{Arc}}$$ (use IMN^2 for TR to obtain best results)

Or, ½ the lead point for an arc to radial intercept

Example: If required lead point for arc to radial intercept from 12 NM arc is 16°, then 8° of bank is required to maintain the 12 NM arc.

6.15.9. Teardrop Penetration Calculations.

6.15.9.1. To determine outbound distance for 30° bank turn:

$$\frac{120\ (\text{TR})}{\text{Degrees Between Radials}} = \text{Distance Outbound}$$

6.15.9.2. To determine bank angle required for teardrop (whenever 30° will not work):

$$\frac{60\ (\text{TR})}{\text{Distance Between Radials}} = \text{Degrees of Bank Required}$$

6.15.10. Teardrop Offset Calculations.

$$\frac{120\ (\text{TR})}{\text{Leg Length}} = \text{Offset}$$

6.15.11. Procedure Turn Calculations.

45°/180° Maneuver Distance = (3 X TR) + 2

80°/260° Maneuver Distance = 3 X TR

6.15.12. VDP Calculation.

$$\frac{\text{HAT}}{\text{gradient (normally 300)}} = \text{VDP in NM from end of runway.}$$

Chapter 7

USING NON-DOD/NOAA INSTRUMENT PROCEDURES

7.1. Introduction. The worldwide nature of the Air Force's mission means that Air Force pilots must be prepared to fly to any airport in the world. Most of the destinations we fly to regularly have instrument procedures published in DoD FLIP products; however, we also have to fly into airfields not covered by DoD or NOAA instrument procedures. In those situations, we are sometimes required to use non-DoD/NOAA instrument procedures. These procedures come in many forms; they may be NATO procedures, Jeppesen products, or even a host nation approach. Whatever the form non-DoD products come in, the rules on the use of non-DoD/NOAA products are found in AFI 11-206, *General Flight Rules*.

7.2. AFI 11-206 Guidance. AFI 11-206 defines the term "published approach," and the sub-bullet which specifically refers to non-DoD/NOAA procedures says that a published approach is:

> " Any product not published in a DoD or NOAA FLIP document, but approved by the MAJCOM for which an operational requirement exists. The MAJCOM Terminal Instrument Procedures (TERPs) office must review the product before MAJCOM grants approval. The MAJCOM TERPs office shall inform aircrews when a product does not meet recognized obstruction clearance and (or) flight inspection criteria."

7.2.1. These Rules Apply to All Non-DoD/NOAA Products. Don't overlook one important fact—the Air Force is not singling out Jeppesen products in AFI 11-206. The restrictions in the paragraph quoted above apply to <u>all</u> non-DoD/NOAA instrument approach procedures—Jeppesen just happens to be the company which publishes most of the non-DoD/NOAA approaches we use. Although most of this chapter will deal with material related to Jeppesen products, the rules apply equally to <u>all</u> other non-DoD/NOAA instrument approach procedures.

7.3. Why Must non-DoD/NOAA Products be Reviewed? Non-DoD/NOAA products must be reviewed because the standard used to construct the procedure is not known.

7.3.1. Similar Process; Different Standards. Instrument procedures developed in the United States are developed using United States TERPs criteria—the Air Force and the FAA use the same book and, therefore, the same standard. Once you leave the U.S., different standards are used. Some countries use U.S. standards, some use ICAO standards, some use NATO standards, and some countries just make up their own standards.

7.3.2. Publishing Standards. In order for instrument procedures to be published in DoD or NOAA FLIP, the procedures must pass a stringent set of checks designed to ensure the procedure meets US standards for safety. Other organizations that publish instrument procedures do not perform the same function—they simply publish what is given to them. Therefore, the safety of the underlying procedure has never been verified against the US standard and must be reviewed by a TERPs specialist to make sure there are no dangerous "surprises" for Air Force aircrews.

7.3.3. Host Nation Information. Let's use Jeppesen as an example. When a country develops an instrument procedure, the procedure is made available to the rest of the world via a publication known as the Aeronautical Information Publication (AIP). Publishers then take the information from the host nation's AIP and publish it for use by their customers. So for any given country, the publishers of DoD/NOAA FLIP and commercial companies (such as Jeppesen) get their information from the same source. Unfortunately, that's where all similarity ends.

7.3.4. Commercial Disclaimers. While any procedure published in DoD/NOAA publications is guaranteed to provide obstacle clearance if properly flown, commercial publishers make no such guarantee. For example, here's a portion of Jeppesen's disclaimer which is printed in the front of all of their products:

> "Jeppesen makes no express or implied warranty, and disclaims any liability with respect to the design, adequacy, accuracy, reliability, safety or conformance with government standards or regulations, of any flight procedure prescribed by a government authority, including, but not limited to, any express or implied warranty of merchantability or fitness for a particular purpose."

As was mentioned earlier, the Air Force is not picking on Jeppesen. Jeppesen is highly respected in the aviation community; however, they are strictly a publishing agency. They take locally-developed procedures, print them in the Jeppesen format, and sell them to users worldwide—they only promise to reproduce the AIP information accurately—that's it.

7.4. Determining if the Appropriate Review has been Accomplished. AFI 11-206's guidance is very clear; however, MAJCOM flight directives (MAJCOM supplements to AFI 11-206, 55- and 11-series MCIs and/or MCRs, FCIFs, FCBs, etc.) sometimes provide conflicting guidance. The important thing to remember is that MAJCOM flight directives can never be less restrictive than AF-level guidance. Operational commanders must provide aircrews with the appropriate approved flight publications for the missions they are tasked to fly. As usual though, the last line of defense is the aircraft commander. In the end, it is the responsibility of the aircraft commander to ensure any non-DoD/NOAA approach procedures have been properly reviewed and approved by the MAJCOM.

7.5. Flying Non-DoD/NOAA Procedures. Once you've finally received the appropriate approval to fly a non-DoD/NOAA procedure, the battle is only half over. Now you have to study the procedure carefully in order to execute it properly in flight.

7.5.1. Different Look. Approaches in the United States are all very similar because they are constructed using the same standard. Outside the US, each country can build instrument procedures using their own standards and many times their procedures are very complex and extremely challenging to fly. Publishing agencies (including DoD and commercial companies) are not allowed to change the host nation's procedure.

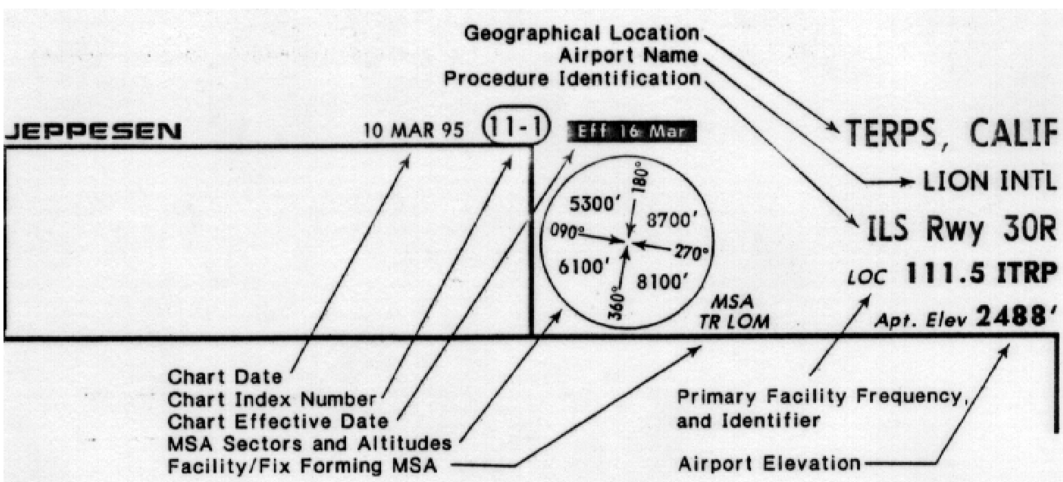
7.5.2. Different Symbology. Host nation procedures and the symbology adopted by commercial companies look different than what we are used to with DoD/NOAA FLIP products. Some of the symbology is very similar; some is significantly different. Although the rest of this chapter will describe Jeppesen symbology (since they publish most of the non-DoD/NOAA procedures we fly), it is important to devote some study time to any non-DoD/NOAA procedure you fly—before you actually fly it.

7.5.3. Different Equipment. Pay careful attention to the equipment required to fly the approach and the missed approach. Outside of the US, it's not uncommon to encounter strange combinations of equipment required to shoot different segments of the approach.

7.6. Jeppesen Approach Charts. Jeppesen approach charts are divided into four main areas: heading, approach plan view, profile view, and landing minimums.

NOTE: For the most current and accurate information, refer to your current Jeppesen Legend. The information presented in this chapter is for training purposes only.

7.6.1. Heading.



7.6.1.1. Chart Date. The chart date is always a Friday date and is used for chart identification purposes.

7.6.1.2. Chart Index Number. Refer to the Jeppesen Approach Chart Legend for the explanation of the chart index number.

7.6.1.3. Chart Effective Date. If the chart was issued prior to changes becoming effective, then the chart will have an effective date. Charts under U.S. jurisdiction become effective at 0901Z on the effective date.

7.6.1.4. MSA Sectors and Altitudes. Minimum Safe Altitude or Minimum Sector Altitude (MSA) provides 1000 feet of obstruction within the circle (or sector) within 25 nautical miles of the facility/fix identified just to the lower right of the circle. If the protected distance is other than 25 nautical miles, the effective radius is stated beside the identifier of the central facility.

7.6.1.5. Facility/Fix Forming MSA. The facility/fix at the center of the MSA circle will be identified here.

7.6.1.6. Geographical Location. The geographical name used is generally the major city served by the civil airport or installation name if a military airport. Charts are arranged alphabetically by the geographical location served. In the United States, the charts are arranged by state and alphabetically within the state.

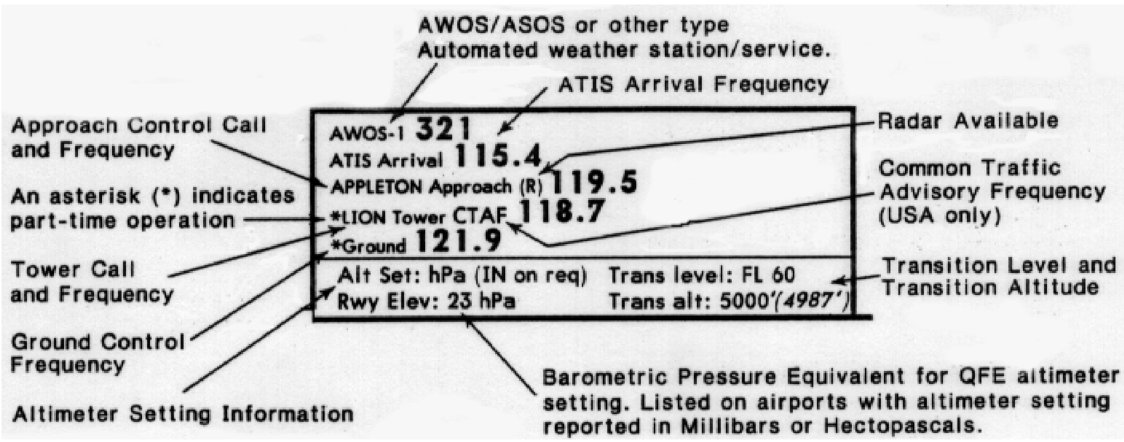
7.6.1.7. Airport Name. The name of the airport is listed under the city name.

7.6.1.8. Procedure Identification. The title of the approach is given below the airport name. This identification is per the applicable authoritative source (ILS RWY 35, VOR or NDB RWY 36, etc.). The use of an alphabetical suffix indicates a procedure does not meet criteria for straight-in landing minimums (e.g. VOR-A, NDB-B, etc.).

7.6.1.9. Primary Facility Frequency and Identifier. Below the approach title, the primary facility's frequency and identification information is displayed.

7.6.1.10. Airport Elevation. The airport elevation is provided below the primary frequency and identifier information.

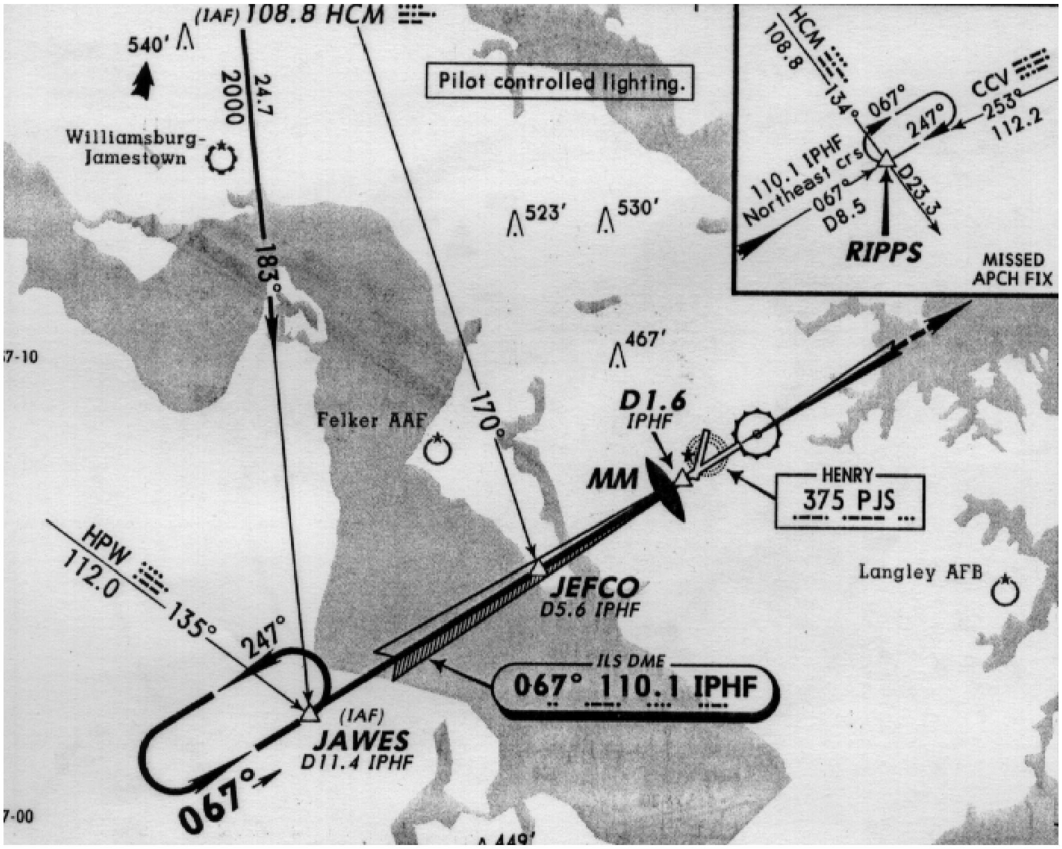
7.6.1.11. Communication and Altimeter Setting Data Box.



7.6.1.11.1. Communication Information. Communication information for "arrivals" are given in the normal sequence of use. An asterisk next to the facility name indicates part-time operation. Letter designations behind a frequency indicate operation as follows: G - Guards Only, T - Transmits Only, and X - On Request. An "R" in parentheses (R) following a facility name indicates radar is available.

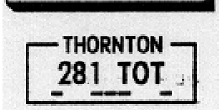
7.6.1.11.2. Altimeter Setting Information. Transition level and transition altitude are provided for all areas outside the 48 conterminous United States, Alaska, and Canada.

7.6.2. Approach Plan View. The approach plan view is a graphic picture of the approach normally presented using a scale of 1 inch = 5 nautical miles. If the scale is different, it will be noted on the chart. Latitude and longitude are shown in 10 minute increments on the plan view neatline.



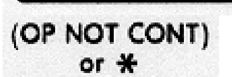
7.6.2.1. Symbology Used in the Approach Plan View. Following are some of the different types of depictions found on Jeppesen charts. This list is not all-inclusive; for complete information, refer to your Jeppesen Legend.

NAVAID Information.

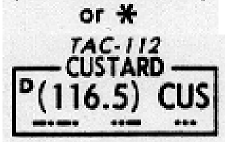


NAVAID facility boxes include facility name, identifier, Morse Code, and frequency. The shadow indicates the primary facility upon which the approach is predicated. In VORTAC and VOR/DME facility boxes the letter "D" indicates DME capability. Refer to the Flight Information Handbook (FIH) for VOR/DME frequency pairing.

VOR, VORTAC, and VOR/DME class is indicated by a letter "T" (Terminal, "L" (Low Altitude) or "H" (High Altitude) when available.

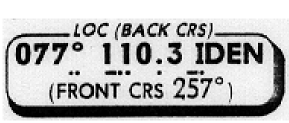


"OP NOT CONT" or an "*" indicates part-time operation.



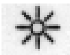
TACAN facility box with "Ghost" VOR frequency for civil tuning of TACAN-only facilities to receive DME information.

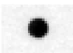
ILS, LOC, LDA, or SDF facility box. It includes inbound magnetic course, frequency, identifier, and Morse code.

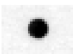


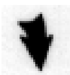
Localizer Back Course facility box. Front course included for HSI setting.

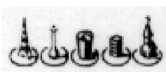
7.6.2.2. Terrain High Points and Man-Made Structures. Some, but not all, terrain high points and man-made structures are depicted, along with their elevation above mean sea level. THIS INFORMATION DOES NOT ASSURE CLEARANCE ABOVE OR AROUND THE TERRAIN OR MAN-MADE STRUCTURES AND MUST NOT BE RELIED ON FOR DESCENT BELOW THE MINIMUM ALTITUDES DICTATED BY THE APPROACH PROCEDURE. Generally, terrain high points and man-made structures less than 400 feet above the airport elevation are not depicted. Here are some of the symbols used to depict terrain high points and man-made structures:

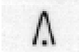

Natural terrain (peak, knoll, hill, etc.). Used prior to 12 Aug 88.


Unidentified natural terrain or man-made. Used prior to 12 Aug 88.

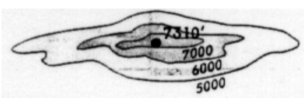

Natural terrain (peak, knoll, hill, etc.). Used after 12 Aug 88.


Arrow indicates only the highest of portrayed TERRAIN HIGH POINTS AND MAN-MADE STRUCTURES in the charted planview. Higher terrain or man-made structures may exist which have not been portrayed.


Man-made (tower, stack, tank, building, church)


Unidentified man-made structure

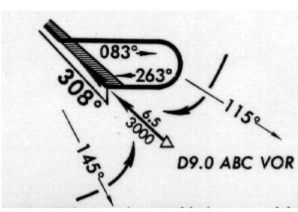
Mean Sea Level elevation at top of TERRAIN HIGH POINT/MAN-MADE STRUCTURE.



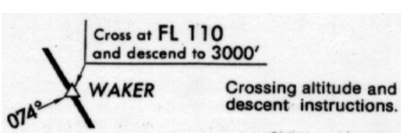
After 24 Jun 94, screened contour lines will be gradually replaced with generalized contour lines, values, and gradient tints printed in brown. Gradient tints indicate the elevation change between contour intervals.

7.6.2.3. Jeppesen Approach Depictions. Not only are different symbols used to depict obstacles and NAVAID information; the way the approach courses, transitions, etc., are depicted is also much different. Following are some of the different depictions; remember, this list is not all-inclusive.

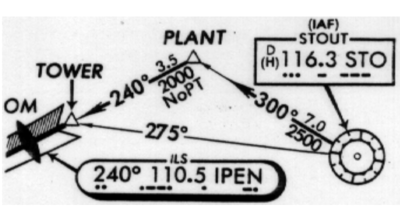
NOTE: When a procedure turn, racetrack pattern, teardrop, or base turn is not portrayed, they are not authorized.



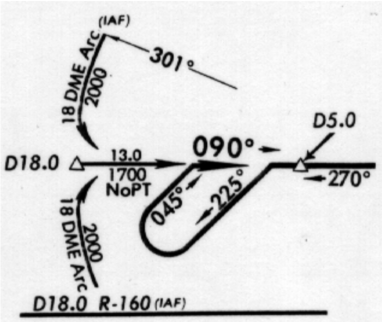
Lead radials may be provided as an advisory point for turning to the approach course.



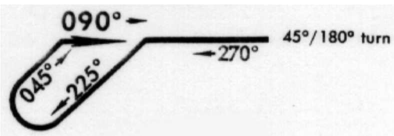
Crossing altitude and descent instructions.



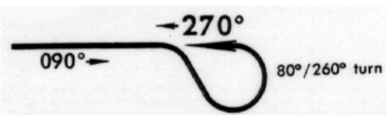
Approach transition track, distance, and altitude from a defined fix is illustrated below. Note that the routes from STO to Plant to Tower are approach transitions, whereas the STO R-275° is not an approach transition. The STO R-275° has a small arrowhead and is a cross radial forming Tower. The STO R-300° has a large and small arrowhead indicating both an approach transition and a cross radial forming Plant. Plant and Tower are also formed by the IPEN localizer course.



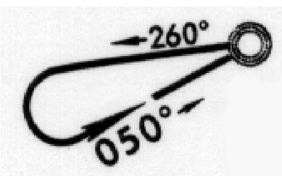
Approach transitions via DME arcs are illustrated with distance from facility, direction of flight, start and termination points of the arc. DME arc altitude is maintained until established on the approach course.



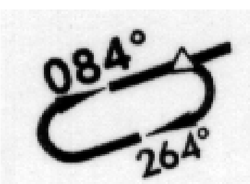
45°/180° procedure turn



80°/260° procedure turn

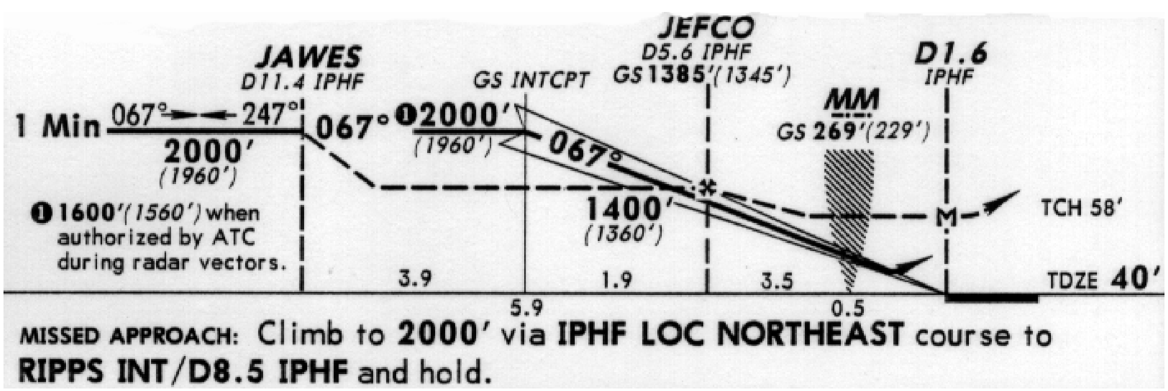


Teardrop or Base Turn. When course reversal is required, it must be flown as charted.



Holding pattern or Racetrack pattern. When course reversal is required, it must be flown as charted.

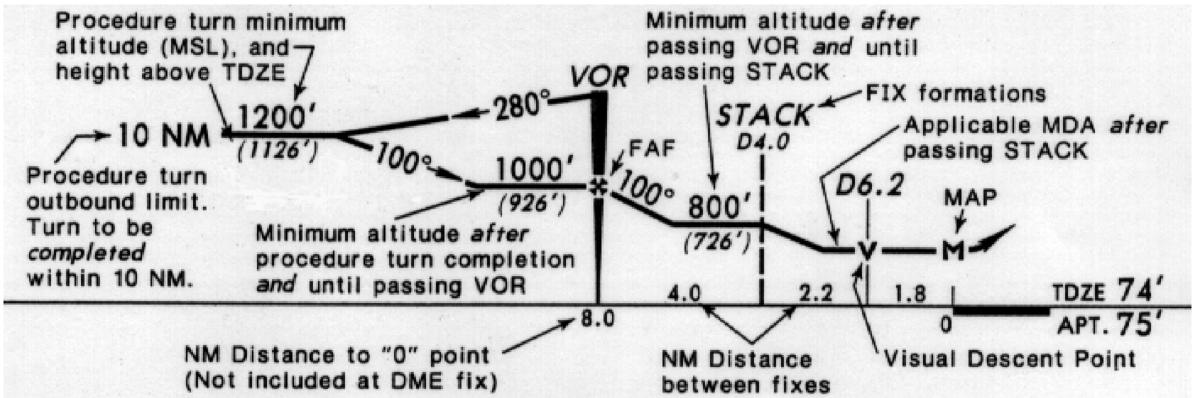
7.6.3. Profile View.



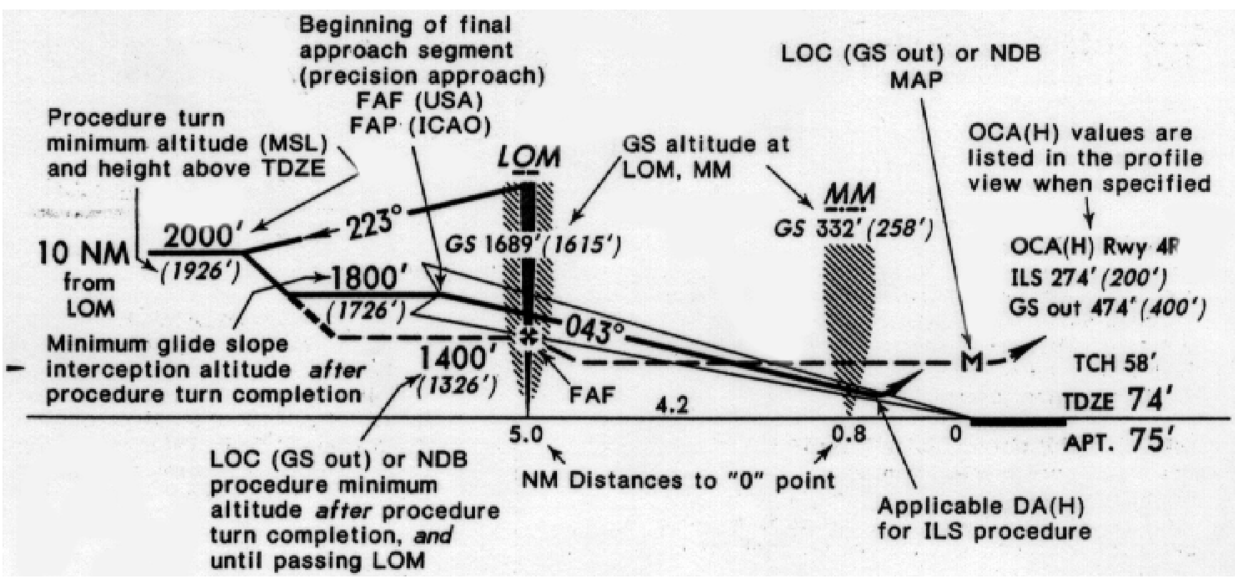
- The top of the profile view on certain non-precision approaches contains a table of recommended altitudes/heights at various DME fixes to allow a constant rate of descent. The altitudes/heights are recommended only; minimum altitudes in the profile view apply.
- Notes pertaining to conditional use of the procedure are shown at the top of the profile. The note “Pilot controlled lighting” indicates that pilot activiation is required as specified on the airport chart under Additional Runway Information.

- The profile view schematically (not to scale) portrays the approach procedure flight track as a vertical cross section of the plan view.

7.6.3.1. Non-Precision Approach Profile (LOC, VOR, NDB, etc.).



7.6.3.2. Precision Approach Profile (ILS with LOC (GS out) or with NDB Approach).



7.6.3.3. Missed Approach. The missed approach procedure text is located immediately below the profile diagram. It may be supplemented by a State specified acceleration altitude/height on charts labeled PANS OPS/PANS OPS 3.

7.6.3.4. Missed Approach Point (MAP). Execute a missed approach:

- **Precision Approaches:** Immediately upon reaching the Decision Altitude (Height) (DA(H)) while descending on the glide slope and continued descent cannot be controlled by visual reference.
- **Non-Precision Approaches:** Upon reaching the missed approach point (MAP). A table at the lower left corner of the chart will specify the MAP and, if applicable, a time at various speeds from fix to MAP. The absence of times in the time/speed table means the MAP cannot be determined by time and a timed approach is Not Authorized. Where a DME Fix is portrayed in addition to a distance, the DME Fix may be used for determining the MAP for DME equipped aircraft. The runway threshold and MAP often coincide.

7.6.3.5. Profile View Altitude Depictions.

2300′

- **Minimum Altitudes.** All altitudes in the profile view are "MINIMUM" altitudes unless specifically labeled otherwise. Altitudes are above mean sea level in feet. May be abbreviated "MIM."

MANDATORY 2400′

- **Mandatory Altitudes.** Mandatory altitudes are labeled "MANDATORY" and mean at the fix or glide slope intercept.

MAXIMUM 1900′

- **Maximum Altitudes.** Maximum altitudes are labeled "MAXIMUM." May be abbreviated "MAX."

RECOMMENDED 2000′

- **Recommended Altitudes.** Recommended altitudes are labeled "RECOMMENDED."

7.6.4. Landing Minimums.

	STRAIGHT-IN LANDING RWY 7					CIRCLE-TO-LAND	
	ILS DA(H) 240′(200′)		LOC (GS out) MDA(H) 420′(380′)				
	FULL	RAIL or ALS out		RAIL out	ALS out	Max Kts	MDA(H)
A	RVR 24 or 1/2	RVR 40 or 3/4	RVR 24 or 1/2	RVR 40 or 3/4	RVR 50 or 1	90	540′(497′)-1
B						120	
C						140	540′(497′)-1 1/2
D			RVR 40 or 3/4	RVR 60 or 1 1/4		165	600′(557′)-2

Gnd speed-Kts	70	90	100	120	140	160
GS 3.00°	377	484	538	646	753	861
MAP at D1.6 IPHF or JEFCO to MAP 4.0	3:26	2:40	2:24	2:00	1:43	1:30

CHANGES: Communications.

7.6.4.1. General. Publication of minimums does not constitute authority for their use by all operators. Each individual operator must obtain appropriate approval for their use.

7.6.4.2. All Charts. All authorized minimums and applicable conditions for each approach procedure are provided within the chart minimum table.

7.6.4.3. Minimums. The first column, at the left, shows the lowest authorized minimum. Succeeding columns to the right will show increasing minimums adjusted to the applicable condition. Installed approach lights or landing aids that affect or may affect minimums are listed in the column headings as "ALS out," "MM out," etc. When two or more installed landing aids are out, the highest "out" condition minimum applies.

7.6.4.4. Altimeter Setting Requirements. Altimeter setting requirements or other special conditions may alter the sequence of the minimums. A review of all notes and minimum box titles should always be made.

7.6.4.5. Sidestep Inoperative Components. For a runway identified as sidestep, such as SIDESTEP RWY 24L: Inoperative light components shown in Rwy 24L column are those for the lights installed on Rwy 24L, not the lights for Rwy 24R.

7.6.4.6. Circling Minimums. Maximum aircraft speeds for circling are shown in lieu of Aircraft Approach Categories starting with charts dated July 28, 1989. Older charts still use Aircraft Approach Categories. The maximum indicated airspeeds are shown in knots.

7.6.4.7. Ceiling Minimums. In some parts of the world a minimum "ceiling" is required as well as a minimum visibility. Ceiling measurement is reported as height above the ground, and therefore, may not be the same value as the height above touchdown (HAT) or height above airport (HAA). The ceiling minimums shown in the minimums format are in feet or meters according to the way they are reported. The ceiling requirement will be highlighted in a black box with the statement "CEILING REQUIRED."

7.6.4.8. Visibility. Visibility for any approach condition is shown below the condition in a band for each aircraft category or each maximum circling speed. Visibility is shown alone, or in addition to RVR. When a governing authority specifies visibility minimums in meters or kilometers, an "m" or "Km" is charted after the specified visibility. When statute or nautical miles are specified, no units are charted; e.g., a specified visibility of "1" means "1 mile."

7.6.4.9. Runway Visual Range (RVR). Runway Visual Range (RVR) is to be used instead of reported visibility for operating on any runway for which RVR is given. The figures shown with RVR represent readings in hundreds of feet, as RVR 24 meaning 2400 feet RVR, or readings in metric units as RVR 550m meaning 550 meters RVR.

7.6.4.10. RVR Visibility Charting. RVR visibility values are charted only when the value is not the same as the prevailing or meteorological visibility value. When a difference occurs, the respective RVR and prevailing or meteorological visibility values are prefixed with “RVR” and “VIS.” When there is no difference, the minimum is shown only once and means either RVR (if RVR is reported for that runway) or visibility if measured otherwise.

7.7. IFR Departure Procedures. Jeppesen products do not indicate the presence of IFR departure procedures in the same manner as DoD/NOAA publications. DoD/NOAA products indicate the presence of IFR departure procedures by placing an inverted black triangle with a white T on the approach plate which are reproduced in the front of the approach plate book. Jeppesen published IFR departure procedures on the airfield diagram page.

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